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Chapter 26 — CD-ROM Content

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- "Building a Modern Signal Tracer" by Curt Terwilliger, W6XJ
- "Hands-on Radio — Power Supply Analysis" by Ward Silver, NØAX
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PC Board Templates

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Chapter 26

Troubleshooting and Maintenance

The robust and self-reliant ethic of Amateur Radio is nowhere stronger than in the amateur's ability to maintain, troubleshoot and repair electronic equipment. Amateurs work with not just radios, but all sorts of equipment from computers and software to antennas and transmission lines. This flexibility and resilience are keys to fulfilling the Basis and Purpose for Amateur Radio.

The sections on troubleshooting approaches, tools and techniques build on earlier material written by Ed Hare, W1RFI. They will help you approach troubleshooting in an organized and effective manner, appropriate to your level of technical experience and tools at hand. This material shows how to get started and ask the right questions — often the most important part of troubleshooting.

Additional sections on troubleshooting power supplies, amplifiers, radios and antenna systems (contributed by Tom Schiller, N6BT, Ted Thrift, VK2ARA, and Ross Pittard, VK3CE) tackle the most common troubleshooting needs. Restoring and maintaining vintage equipment is a popular part of ham radio and so there are some sections by John Fitzsimmons, W3JN, and Pat Bunsold, WA6MHZ, on the special needs of this equipment.

This chapter is organized in three groups of sections to be consulted as required for any particular troubleshooting need. You will not need to read it from end-to-end in order to troubleshoot successfully. The first group of sections covers test equipment details, pertinent information about components, and safety practices. The second group presents general guidelines and techniques for effective troubleshooting. The third group presents specific advice and information on equipment that is commonly repaired by amateurs.

TROUBLESHOOTING — ART OR SCIENCE?

Although some say troubleshooting is as much art as it is science, the repair of electronic gear is not magic. It is more like detective work as you work carefully to uncover each clue. Knowledge of advanced math or electronics theory is not required. However, you must have, or develop, a good grasp of basic electronics and simple measurements, guided by the ability to read a schematic diagram and to visualize signal flow through the circuit. As with most skills, these abilities will develop with practice.

Not everyone is an electronics wizard; your gear may end up at the repair shop in spite of your best efforts. The theory you learned for the FCC examinations and the information in this *Handbook* can help you decide if you can fix it yourself. Even if the problem appears to be complex, most problems have simple causes. Why not give troubleshooting a try to the best of your abilities? Maybe you can avoid the effort and expense of shipping the radio to the manufacturer. It is gratifying to save time and money, but the experience and confidence you gain by fixing it yourself may prove even more valuable.

SAFETY FIRST! — SWITCH TO SAFETY

Always! Death is permanent. A review of safety must be the first thing discussed in a troubleshooting chapter. Some of the voltages found in amateur equipment can be fatal! Only 50 mA flowing through the body is painful; 100 to 500 mA is usually fatal. Under certain conditions, as little as 24 V can kill. RF exposure in a high-power amplifier can create severe burns very quickly. Batteries can deliver huge amounts of power that can melt tools and wires or create an explosion when short-circuited. Charging lead-acid cells can create a buildup of explosive hydrogen gas, as well.

Make sure you are 100% familiar with all safety rules and the dangerous conditions that might exist in the equipment you are servicing. A list of safety rules can be found in **Table 26.1**. You should also read the **Safety** chapter of this *Handbook* — all of it — before you begin to work on equipment.

Remember, if the equipment is not working properly, dangerous conditions may exist where you don't expect them. Treat every component as potentially "live." Some older equipment uses "ac/dc" circuitry. In this circuit, one side of the chassis is connected directly to the ac line, a condition unexpected by today's amateurs who are accustomed to modern safety standards and practices. This is an electric shock waiting to happen.

The maximum voltage rating of voltmeters and oscilloscopes is not often noted by the hobbyist but it is crucial to safety when working on voltages higher than the household ac line voltage. Test equipment designed to measure voltage always has a maximum safe voltage rating

Table 26.1
Safety Rules

1. Keep one hand in your pocket when working on live circuits or checking to see that capacitors are discharged.
2. Include a conveniently located ground-fault current interrupter (GFCI) circuit breaker in the workbench wiring.
3. Use only grounded plugs and receptacles.
4. Use a GFCI protected circuit when working outdoors, on a concrete or dirt floor, in wet areas, or near fixtures or appliances connected to water lines, or within six feet of any exposed grounded building feature.
5. Use a fused, power limiting isolation transformer when working on ac/dc devices.
6. Switch off the power, disconnect equipment from the power source, ground the output of the internal dc power supply, and discharge capacitors when making circuit changes.
7. Do not subject electrolytic capacitors to excessive voltage, ac voltage or reverse voltage.
8. Test leads should be well insulated and without cracks, fraying, or exposed conductors
9. Do not work alone!
10. Wear safety glasses for protection against sparks and metal or solder fragments.
11. Be careful with tools that may cause short circuits.
12. Replace fuses only with those having proper ratings.
13. Never use test equipment to measure voltages above its maximum rating.

between the circuit being measured and the equipment user — you! This is particularly important in handheld equipment in which there is no metal enclosure connected to an ac safety ground. Excessive voltage can result in a flashover to the user from the internal electronics, probes, or test leads, resulting in electric shock. Know and respect this rating.

If you are using an external high voltage probe, make sure it is in good condition with no cracks in the body. The test lead insulation should be in good condition — flexible and with no cracks or wire exposed. If practical, do not make measurements while holding the probe or meter. Attach the probe with the voltage discharged and then turn the power on. Turn power off and discharge the voltage before touching the probe again. Treat high voltage equipment with care and respect!

Soldering Safety

Remember that soldering tools and melted solder can be hot and dangerous! Wear protective goggles and clothing when soldering. A full course in first aid is beyond the scope of this chapter, but if you burn your skin, run the burn immediately under cold water and seek first aid or medical attention. Always seek medical attention if you burn your eyes; even a small burn can develop into serious trouble.

UNDERSTANDING THE BASICS

To fix electronic equipment, you need to understand the system and circuits you are troubleshooting. A working knowledge of electronic theory, circuitry and components is an important part of the process. When you are troubleshooting, you are looking for specific conditions that cause the symptoms you are experiencing. Knowing how circuits are supposed to work will help you to notice things that are out of place or that indicate a problem.

To be an effective troubleshooter, review and understand the following topics discussed elsewhere in this book:

• Ohms law and basic resistor circuits (**Electrical Fundamentals**)

• Basic transistor and diode characteristics (**Analog Basics**)

• Fundamental digital logic and logic signals (**Digital Basics**)

• Voltage and current measurements (**Test Equipment and Measurements**)

• SWR and RF power measurement (**Transmission Lines**)

You would be surprised at how many problems — even problems that appear complicated — turn out to have a simple root cause found by understanding the fundamentals and methods of one of these categories.

GETTING HELP

Other hams may be able to help you with your troubleshooting and repair problems, either with a manual or technical help. Check with your local club or repeater group. You may get lucky and find a troubleshooting wizard. (On the other hand, you may get some advice that is downright dangerous, so be selective.) Most clubs have one or two troubleshooting gurus who can provide guidance and advice, if not some on-the-workbench help.

There is a wealth of information available online, too. Many of the popular brands of equipment and even specific models have their own online communities or user's groups. The archives of these groups — almost universally free to join — contain much valuable troubleshooting, modification and operating information. If the problem doesn't appear to have been described, you can ask the group.

The Technology area of the ARRL's website also has an extensive section on Servicing Equipment (**www.arrl.org/servicing-equipment**). That page features articles and other resources, including links to schematic databases.

Your fellow hams in the ARRL Field organization may also help. Technical Coordinators (TC) and Technical Specialists (TS) are volunteers who are willing to help hams with technical questions. For the name and address of a local TC or TS, contact your Section Manager (listed in the front of any recent issue of *QST*).

Using Search Engines for Troubleshooting

The power of Internet search engines can save huge amounts of time when troubleshooting equipment. The key is in knowing how to construct the right list of words for them to find. Precision is your friend — be exact and use words others are likely to use if they had the same problem. Use the primary model number without suffixes to avoid being too specific. For example, when troubleshooting the well-known PLL potting compound problem exhibited by Kenwood TS-440 transceivers, entering the search string "TS-440 display dots" immediately finds many web pages dealing with the problem, while simply entering "Kenwood transceiver blank display" returns dozen of unrelated links.

Start with a very specific description of the problem and gradually use less exact terms if you don't find what you want. Learn how to use the "Advanced Search" functions of the search engine, too.

26.1 Test Equipment

Many of the steps involved in effiicient troubleshooting require the use of test equipment. We cannot see electricity directly, but we can measure its characteristics and effects. Our test equipment becomes our electrical senses.

The **Test Equipment and Measurements** chapter is where you can find out more about various common types of equipment, how to operate it, and even how to build some of your own. There are many articles in *QST* and in books and websites that explain test equipment and offer build-it-yourself projects, too. Surplus equipment of excellent quality is widely available at a fraction of its new cost.

You need not purchase or build every type of test equipment. Specialty equipment such as spectrum analyzers or UHF frequency counters can often be borrowed from a club member or friend — maybe one of those troubleshooting gurus mentioned earlier. If you own the basic instruments and know how to use them, you'll be able to do quite a bit of troubleshooting before you need the special instruments.

26.1.1 Senses

Although they are not test equipment in the classic sense, your own senses will tell you as much about the equipment you are trying to fix as the most-expensive spectrum analyzer. We each have some of these natural test instruments.

Eyes — Use them constantly. Look for evidence of heat and arcing, burned components, broken connections or wires, poor solder joints or other obvious visual problems.

Ears — Severe audio distortion can be detected by ear. The snaps and pops of arcing or the sizzling of a burning component may help you track down circuit faults. An experienced troubleshooter can diagnose some circuit problems by the sound they make. For example, a bad audio-output IC sounds slightly different from a defective speaker.

Nose — Your nose can tell you a lot. With experience, the smells of ozone, an overheating transformer, and a burned resistor or PC board trace each become unique and distinctive. Many troubleshooting sessions begin with "something smells hot!"

Finger — After using a voltmeter to ensure no hazardous voltages are present, you can use a fingertip to determine low heat levels— never do this in a high-voltage circuit. Use a temperature probe if using a finger is unsafe. Small-signal transistors can be fairly warm, but being very hot indicates a circuit problem. Warm or hot capacitors are always suspect. High-power devices and resistors can be quite hot during normal operation.

Brain — More troubleshooting problems have been solved with a multimeter and a brain than with the most expensive spectrum analyzer. You must use your brain to analyze data collected by other instruments.

26.1.2 Internal Equipment

Some test equipment is included in the equipment you repair. Nearly all receivers include a speaker. An S meter is usually connected ahead of the audio chain. If the S meter shows signals, that indicates that the RF and IF circuitry is probably functioning. Transmitters often have a power supply voltage and current meter, along with power output, SWR, ALC and speech compression readings that give valuable clues about what is happening inside the equipment.

The equipment also has visual indicator lights that provide additional information such as transmit status, high SWR, low voltage, squelch status, and so forth. These readings or indicators are often specifically referenced by the troubleshooting sections of manuals to help sort out problems.

Microprocessor-controlled equipment often provides error indications, either through a display or by indicator lights. In addition, faults detected by the control software are sometimes communicated through patterns of beeps or flashing of LEDs. Each sequence has a specific meaning that is described in the operating or service manual.

26.1.3 Bench Equipment

The following is a list of the most common and useful test instruments for troubleshooting. Some items serve several purposes and may substitute for others on the list. The theory and operation of most of this equipment is discussed in detail in the **Test Equipment and Measurements** chapter. Notes about the equipment's use for troubleshooting are listed here.

Multimeters —The most often used piece of test equipment, the digital multimeter or DMM, can often test capacitors of most values in addition to voltage, current and resistance. Most can test diodes and transistors on a go/no-go basis, while some can measure gain. Some can even measure frequency or use an external probe to measure temperature.

Some DMMs are affected by RF, so most technicians keep an old-style analog moving-needle VOM (volt-ohm-meter) on hand for use in strong RF fields. Some technicians prefer the moving needle for peaking or nulling adjustments.

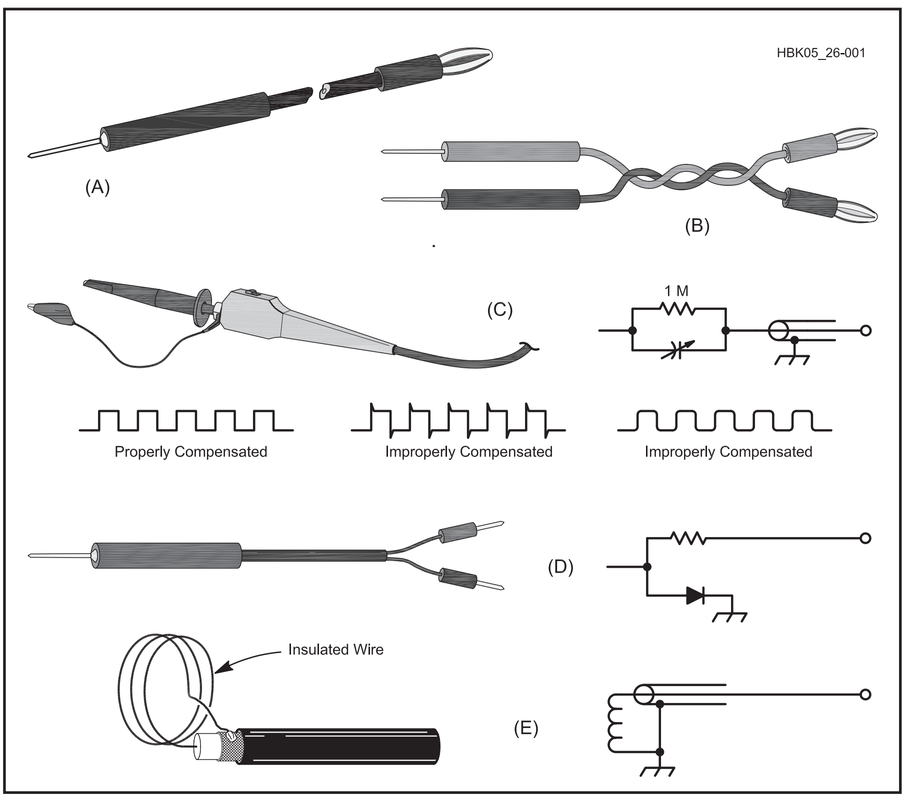

Fig 26.1 — An array of test probes for use with various test instruments.

Fig 26.2 — A clamp-on meter probe is used with a digital multimeter for measuring ac current (left). Meters are also available integrated with the clamp-on probe (right).

Test or clip leads — Keep an assortment of these wires with insulated alligator clips. Commercially-made leads have a high failure rate because they use small wire that is not soldered to the clips, just crimped. You can slip off the clip jackets and solder the wire yourself for better reliability. Making a set of heavier-gauge leads is a good idea for currents above several hundred milliamps.

Individual wire leads (**Fig 26.1A**) are good for dc measurements, but they can pick up unwanted RF energy. This problem is reduced somewhat if the leads are twisted together (Fig 26.1B). Coaxial cable test leads can avoid RF pickup but also place a small capacitance across the circuit being measured. The added capacitance may affect performance.

Test probes — The most common probe is the low-capacitance (×10) oscilloscope probe shown in Fig 26.1C. This probe isolates the oscilloscope from the circuit under test, preventing the scope's input and test-probe capacitance from affecting the circuit and changing the reading. A network in the probe serves as a 10:1 divider and compensates for frequency distortion in the cable and test instrument.

Demodulator probes (see the **Test Equipment and Measurements** chapter and the schematic shown in Fig 26.1D) are used to demodulate or detect RF signals, converting modulated RF signals to audio that can be heard in a signal tracer or seen on a low-bandwidth scope.

You can make a probe for inductive coupling as shown in Fig 26.1E. Connect a two or three-turn loop across the center conductor and shield before sealing the end. The inductive pickup is useful for coupling to high-current points and can also be used as a sniffer probe to pick up RF signals without contacting a circuit directly.

Other common types of probes are the non-contact clamp-on probes shown in **Fig 26.2** that use magnetic fields to measure current. A high-voltage probe for use with DMMs or VOMs is shown in **Fig 26.3** and is discussed more in this chapter's section on power supply troubleshooting.

Thermocouple and active temperature sensor probes are also commonly available. These display temperature directly on the meter in °F or °C.

RF power and SWR meters — Simple meters indicate relative power SWR and are fine for adjusting matching networks and monitoring transmission line conditions for problems. However, if you want to make accurate measurements, a calibrated directional RF wattmeter with the proper sensing elements for the frequencies of signals being measured is required.

Dummy load — Do not put a signal on the air while repairing equipment. Defective equipment can generate signals that interfere with other hams or other radio services. A dummy load also provides a known, matched load (usually 50 Ω) for use during adjustments and test measurements. See the **Transmitters and Transceivers** chapter.

Dip meter — As described in the **Test Equipment and Measurements** chapter, dip meters are used to adjust and troubleshoot resonant circuits. Many can perform as an absorption frequency meter, as well. Dip meters can be used as low-power signal sources but are not very stable.

New dip meters are fairly rare. When purchasing a dip meter, look for one that is mechanically and electrically stable. All of the coils should be present and in good condition. A headphone connection is helpful. Battery operated models are easier to use for antenna measurements. Dip meters are not nearly as common as they once were.

Oscilloscope — The oscilloscope, or scope, is the second most often used piece of test equipment, although a lot of repairs can be accomplished without one. The trace of a scope can give us a lot of information about a signal at a glance. For example, when signals from the input and output of a stage are displayed on a dual-trace scope, stage linearity and phase shift can be checked (see **Fig 26.4**).

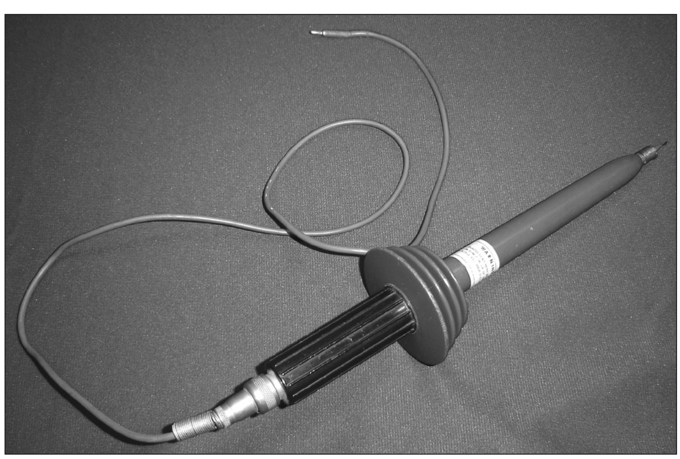

Fig 26.3 — A probe used for measuring high-voltage with a standard multimeter.

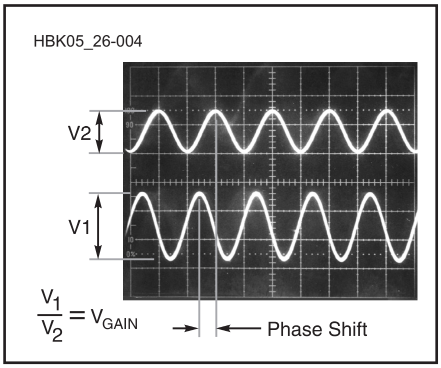

Fig 26.4 — A dual-trace oscilloscope display of amplifier input and output waveforms.

An oscilloscope will show gross distortions of audio and RF waveforms, but it cannot be used to verify that a transmitter meets FCC regulations for harmonics and spurious emissions. Harmonics that are down only 20 dB from the fundamental would be illegal in most cases, but they would not change the oscilloscope waveform enough to be seen.

When buying a scope, get the highest bandwidth you can afford. Old Hewlett-Packard or Tektronix instruments are usually quite good for amateur use.

Signal generator — Although signal generators have many uses, in troubleshooting they are most often used for signal injection (more about this later) and alignment of vintage equipment.

When buying a generator, look for one that can generate a sine wave signal. A good signal generator is double or triple shielded against leakage. Fixed-frequency audio should be available for modulation of the RF signal and for injection into audio stages. The most versatile generators can generate amplitude and frequency modulated signals. Used Hewlett-Packard and Tektronix units are typically available for reasonable prices but may not be repairable if they fail due to unavailable parts.

Good generators have stable frequency controls with no backlash. They also have multiposition switches to control signal level. A switch marked in dBm is a good indication that you have located a high-quality test instrument. The output jack should be a coaxial connector (usually a BNC or N), not the kind used for microphone connections.

In lieu of a fully tunable generator, you can build some simple equipment that generates a signal. For example, Elecraft makes the XG3 kit — a programmable signal source (**www.elecraft.com**) that generates 160 through 2 meter signals with four calibrated output levels. It's very useful for receiver calibration, sensitivity tests and signal tracing.

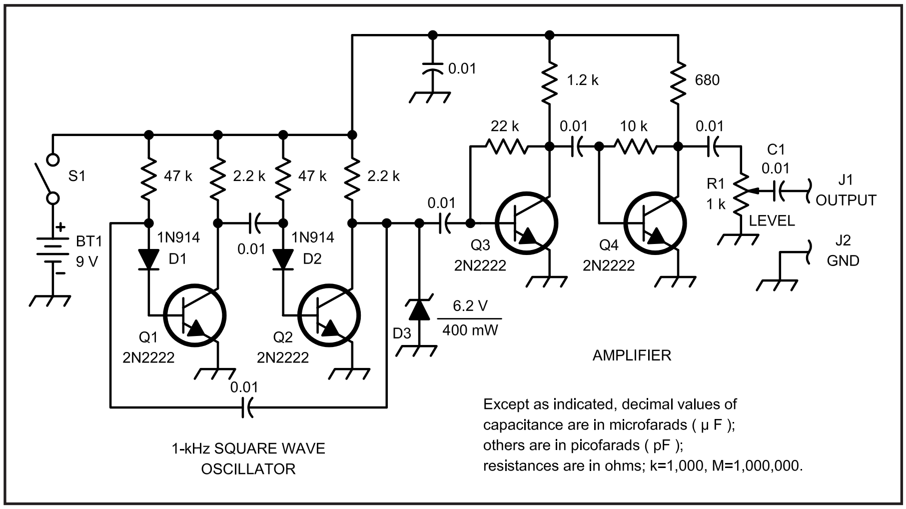

Fig 26.5 — Schematic of the AF/RF signal injector. All resistors are ¼ W, 5% carbon units, and all capacitors are disc ceramic. A full-size etching pattern and parts-placement diagram can be found in the Supplemental Files section of the *Handbook* CD-ROM.

BT1 — 9 V battery.
D1, D2 — Silicon switching diode, 1N914 or equiv.
D3 — 6.2 V, 400 mW Zener diode.
J1, J2 — Banana jack.
Q1-Q4 — General-purpose silicon NPN transistors, 2N2222 or similar.
R1 — 1 kΩ panel-mount control.
S1 — SPST toggle switch.

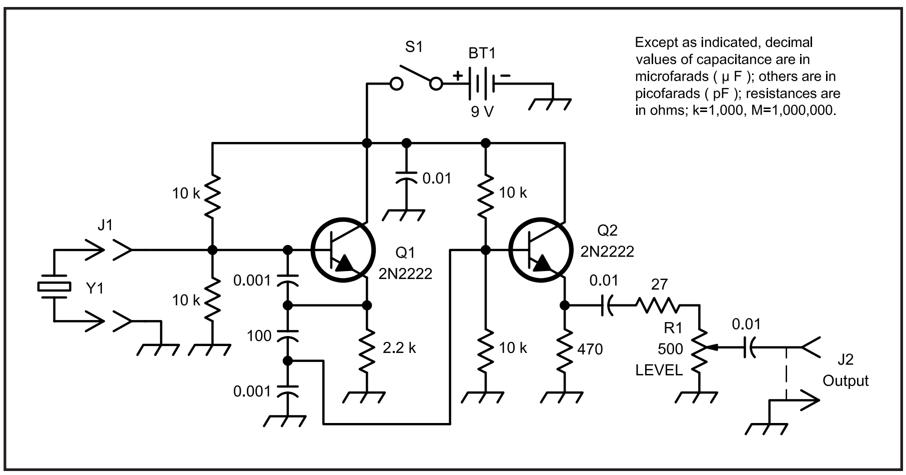

Fig 26.6 — Schematic of the crystal-controlled signal source. All resistors are ¼ W, 5% carbon units, and all capacitors are disc ceramic. A full-size etching pattern and parts-placement diagram can be found in the Supplemental Files section of the *Handbook* CD-ROM.

BT1 — 9 V transistor radio battery.
J1 — Crystal socket to match the crystal type used.
J2 — RCA phono jack or equivalent.
Q1, Q2 — General-purpose silicon NPN transistors, 2N2222 or similar.
R1 — 500 Ω panel-mount control.
S1 — SPST toggle switch.
Y1 — 1 to 15-MHz crystal.

Even simpler, you can homebrew the AF/RF signal-injector schematic as shown in **Fig 26.5**. If frequency accuracy is needed, the crystal-controlled signal source of **Fig 26.6** can be used. The AF/RF circuit provides usable harmonics up to 30 MHz, while the crystal controlled oscillator will function with crystals from 1 to 15 MHz. These two projects are not meant to replace standard signal generators for alignment and precision testing, but they are adequate for generating signals that can be used for general troubleshooting. (See the section on Signal Tracing and Signal Injection.)

Signal tracer — Signals can be traced with a voltmeter and an RF probe, a dip meter with headphones or an oscilloscope, but signal tracers combine these functions especially for signal tracing through a receiver or other RF signal processing circuit. Articles describing the use of signal tracers, including a project you can build yourself, are provided on the CD-ROM that comes with this book.

A general-coverage receiver can be also used to trace RF or IF signals, if the receiver covers the necessary frequency range. Most receivers, however, have a low-impedance input that severely loads the test circuit. To minimize loading, use a capacitive probe or loop pickup as in Fig 26.1. When the probe is held near the circuit, signals will be picked up and carried to the receiver. It may also pick up stray RF, so make sure you are listening to the correct signal by switching the circuit under test on and off while listening.

Transistor tester — Most transistor failures appear as either an open or shorted junction. Opens and shorts can be found easily with an ohmmeter or the diode junction checker of a standard DMM; a special tester is not required.

Transistor testers measure device current while the device is conducting or while an ac signal is applied at the control terminal. Transistor gain characteristics vary widely even between units with the same device number. Testers can be used to measure the gain of a transistor. DMM testers measure only transistor dc alpha and beta. Testers that apply an ac signal show the ac alpha or beta. Better testers also test for leakage.

In addition to telling you whether a transistor is good or bad, a transistor tester can help you decide if a particular transistor has sufficient gain for use as a replacement. It may also help when matched transistors are required. The final test is the repaired circuit.

Frequency counter — Most inexpensive frequency counters display frequency with 1 Hz resolution or better up to around low VHF frequencies. Some may include a prescaler that divides higher frequencies by 10 to extend the counter's range. Good quality used counters are widely available.

Power supplies — A well-equipped test bench should include a means of varying the ac-line voltage, a variable-voltage regulated dc supply and an isolation transformer.

AC-line voltage varies slightly with load. An autotransformer with a movable tap (also known by the trade name Variac) lets you boost or reduce the line voltage slightly. This is helpful to test circuit functions with supply-voltage variations.

An isolation transformer is required to work safely on vintage equipment that often ties one side of the ac line to the chassis. An isolation transformer is also required when working on any equipment or circuits that operate directly connected to the line. Note that your test equipment will also have to be powered through the isolation transformer in such cases!

A good multi-voltage supply will help with nearly any analog or digital troubleshooting project. Many electronics distributors stock bench power supplies. A variable-voltage dc supply may be used to power various small items under repair or provide a variable bias supply for testing active devices. Construction details for a laboratory power supply appear in the **Power Sources** chapter.

Heat and cold sources — Many circuit problems are sensitive to temperature. A piece of equipment may work well when first turned on (cold) but fail as it warms up. In this case, a cold source will help you find the intermittent connection. When you cool the bad component, the circuit will suddenly start working again (or stop working). Cooling sprays are available from most parts suppliers.

A heat source helps locate components that fail only when hot. A small incandescent lamp can be mounted in a large piece of sleeve insulation to produce localized heat for test purposes. The tip of a soldering iron set to low heat can also be used.

A heat source is usually used in conjunction with a cold source. If you have a circuit that stops working when it warms up, heat the circuit until it fails, then cool the components one by one. When the circuit starts working again, the last component sprayed was the bad one.

Stethoscope — A stethoscope (with the pickup removed — see **Fig 26.7**) or a long piece of sleeve insulation can be used to listen for arcing or sizzling in a circuit. Remove any metal parts at the end of the pickup tube before use for troubleshooting live equipment.

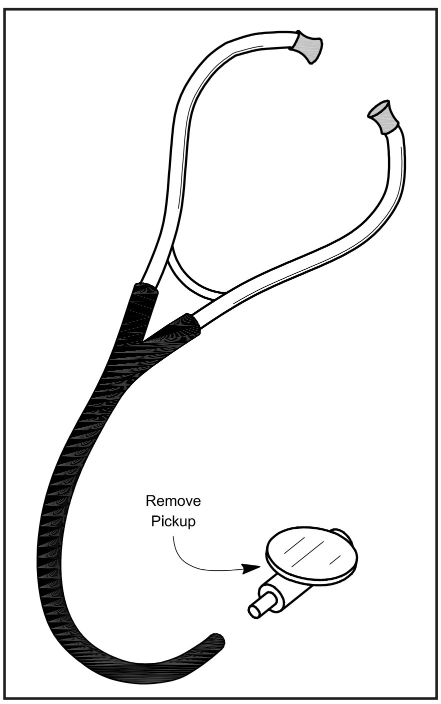

Fig 26.7 — A stethoscope, with the pickup and all metal hardware removed from the listening tube, is used to listen for arcing in crowded circuits.

The Shack Notebook

A shack notebook is an excellent way to keep track of test results, wiring, assembly notes and so forth. If you haven't already started one, now is a good time. All it takes is an inexpensive composition book or spiral-bound notebook. The books filled with graph paper are especially good for drawing and making graphs.

The goal is to have one place where information is collected about how equipment was built, performs, or operates. The notebook is invaluable when trying to determine if performance has changed over time or what color code was used for a control cable, for example.

Before beginning a test session or when adding a new piece of equipment to your shack, get out the shack notebook first and have it available as you work. For new equipment, record serial numbers, when installed, whether it was modified or specially configured to work in your station, etc. For a new antenna or feed line, it's a good idea to make a few SWR measurements so you can refer to them later if something seems wrong in the antenna system. Be sure to include the date of any entries, as well.

You can also make good use of that digital camera, even the one in your mobile phone. Take pictures of equipment, inside and out, to document how it is assembled or configured. This can be very helpful when you have to maintain the equipment later.

26.2 Components

Once you locate a defective part, it is time to select a replacement. This is not always an easy task. Each electronic component has a function. This section acquaints you with the functions, failure modes and test procedures of resistors, capacitors, inductors and other components. Test the components implicated by symptoms and stage-level testing. In most cases, a particular faulty component will be located by these tests. If a faulty component is not indicated, check the circuit adjustments. As a last resort, use a "shotgun" approach — replace all parts in the problem area with components that are known to be good.

26.2.1 Check the Circuit

Before you install a replacement component of any type, you should be sure that another circuit defect didn't cause the failure. Check the circuit voltages carefully before installing any new component, especially on each trace or connection to the bad component. The old part may have died as a result of a lethal voltage. Measure twice — repair once! (With apologies to the old carpenter...) Of course, circuit performance is the final test of any substitution.

26.2.2 Fuses

Most of the time, when a fuse fails, it is for a reason — usually a short circuit in the load. A fuse that has failed because of a short circuit usually shows the evidence of high current: a blackened interior with little blobs of fuse element everywhere. Fuses can also fail by fracturing the element at either end. This kind of failure is not visible by looking at the fuse. Check even fuses thought to be good with an ohmmeter. You may save hours of troubleshooting.

For safety reasons, always use *exact* replacement fuses. Check the current and voltage ratings. The fuse timing (fast, normal or slow blow) must be the same as the original. Never attempt to force a fuse that is not the right size into a fuse holder. The substitution of a bar, wire or penny for a fuse invites a smoke party.

26.2.3 Wires and Cables

Wires seldom fail unless abused. Short circuits can be caused by physical damage to insulation or by conductive contamination. Damaged insulation is usually apparent during a close visual inspection of the conductor or connector. Look carefully where conductors come close to corners or sharp objects. Repair worn insulation by replacing the wire or securing an insulating sleeve (spaghetti) or heat-shrink tubing over the worn area.

When wires fail, the failure is usually caused by stress and flexing. Nearly everyone has broken a wire by bending it back and forth, and broken wires are usually easy to detect. Look for sharp bends or bulges in the insulation.

When replacing conductors, use the same material and size, if possible. Substitute only wire of greater cross-sectional area (smaller gauge number) or material of greater conductivity. Insulated wire should be rated at the same, or higher, temperature and voltage as the wire it replaces.

Cables used for audio, control signals, and feed lines sometimes fail from excessive flexing, being crimped or bent too abruptly, or getting pulled out of connectors. As with replacing wires, use the same cable type or one with higher ratings.

26.2.4 Connectors

Connection faults are one of the most common failures in electronic equipment. This can range from something as simple as the ac-line cord coming out of the wall, to a connector having been inserted into the wrong socket, to a defective IC socket. Connectors that are plugged and unplugged frequently can wear out, becoming intermittent or noisy. Inspect male connectors for bent pins, particular miniature connectors with very small pins. Check connectors carefully when troubleshooting.

Connector failure can be hard to detect. Most connectors maintain contact as a result of spring tension that forces two conductors together. As the parts age, they become brittle and lose tension. Any connection may deteriorate because of nonconductive corrosion at the contacts. Solder helps prevent this problem but even soldered joints suffer from corrosion when exposed to weather.

Signs of excess heat are sometimes seen near poor connections in circuits that carry moderate current. The increase in dissipated power at the poor connection heats the contacts, and this leads to more resistance and soon the connection fails. Check for short and open circuits with an ohmmeter or continuity tester. Clean those connections that fail as a result of contamination.

Occasionally, corroded connectors may be repaired by cleaning, but replacement of the conductor/connector is usually required, especially for battery holders supplying moderate currents. Solder all connections that may be subject to harsh environments and protect them with acrylic enamel, RTV compound or a similar coating. An anti-corrosion compound or grease is a good idea for connections located outside. See the entry on Weatherproofing RF Connectors in the Antenna and Tower Safety section of the **Safety** chapter.

Choose replacement connectors with consideration of voltage and current ratings. Use connectors with symmetrical pin arrangements only where correct insertion will not result in a safety hazard or circuit damage.

26.2.5 Resistors

Resistors usually fail by becoming an open circuit. More rarely they change value. Both failures are usually caused by excess heat. Such heat may come from external sources or from power dissipated within the resistor. Sufficient heat burns the resistor until it becomes an open circuit.

Resistors can also fracture and become an open circuit as a result of physical shock. Contamination on or around a high-value resistor (100 kΩ or more) can cause a change in value by providing a leakage path for current around a resistor. This contamination can occur on the resistor body, mounts or printed-circuit board. Resistors that have changed value should be replaced. Leakage is cured by cleaning the resistor body and surrounding area.

In addition to the problems of fixed-value resistors, potentiometers and rheostats can develop noise problems, especially in dc circuits. Dirt often causes intermittent contact between the wiper and resistive element. To cure the problem, spray electronic contact cleaner into the control, through holes in the case, and rotate the shaft a few times.

The resistive element in wire-wound potentiometers eventually wears and breaks from the sliding action of the wiper. In this case, the control needs to be replaced.

Replacement resistors should be of the same value, tolerance, type and power rating as the original. The value should stay within tolerance. Replacement resistors may be of a different type than the original, if the characteristics of the replacement are consistent with circuit requirements. (See the **Electrical Fundamentals** chapter for more information on resistor types.)

Substitute resistors can usually have a greater power rating than the original, except in high-power emitter circuits where the resistor also acts as a fuse or in cases where the larger size presents a problem.

Variable resistors should be replaced with the same kind (carbon or wire wound) and taper (linear, log, reverse log and so on) as the original. Keep the same, or better, tolerance and pay attention to the power rating.

In all cases, mount high-temperature resistors away from heat-sensitive components. Keep carbon composition and film resistors away from heat sources. This will extend their life and ensure minimum resistance variations.

26.2.6 Capacitors

Capacitors usually fail by shorting, opening or becoming electrically (or physically) leaky. They rarely change value. Capacitor failure is usually caused by excess current, voltage, temperature or aging of the dielectric or materials making up the capacitor. Leakage can be external to the capacitor (contamination on the capacitor body or circuit) or internal to the capacitor.

TESTS

If you do not have a multimeter with a capacitor test function or a component tester, the easiest way to test capacitors is out of circuit with an ohmmeter. In this test, the resistance of the meter forms a timing circuit with the capacitor to be checked. Capacitors from 0.01 µF to a few hundred µF can be tested with common ohmmeters. Set the meter to its highest range and connect the test leads across the discharged capacitor. When the leads are connected, current begins to flow. Current is high when the capacitor is discharged, but drops as the capacitor voltage builds up. This shows on the meter as a low resistance that builds, over time, toward infinity.

The speed of the resistance build-up corresponds to capacitance. Small capacitance values approach infinite resistance almost instantly. A 0.01 µF capacitor checked with a meter having an 11 MΩ input impedance would increase from zero to a two-thirds scale reading in 0.11 second, while a 1 µF unit would require 11 seconds to reach the same reading. If the tested capacitor does not reach infinity within five times the period taken to reach the two-thirds point, it has excess leakage. If the meter reads infinite resistance immediately, the capacitor is open. (Aluminum electrolytics normally exhibit high-leakage readings.)

Capacitance can also be measured for approximate value with a dip meter by constructing a parallel-resonant circuit using an inductor of known value. The formula for resonance is discussed in the **Electrical Fundamentals** chapter of this book.

It is good practice to keep a collection of known components that have been measured on accurate L or C meters. Alternatively, a standard value can be obtained by ordering 1 or 2% components from an electronics supplier. A 10% tolerance component can be used as a standard; however, the results will be known only to within 10%. The accuracy of tests made with any of these alternatives depends on the accuracy of the standard value component. Further information on this technique appears in Bartlett's article, "Calculating Component Values," in Nov 1978 *QST*.

Older capacitors can also be checked and the dielectric reformed, if necessary, with a capacitor checker of similar vintage. See this chapter's section on Restoration and Repair of Vintage Radios for more information about this technique.

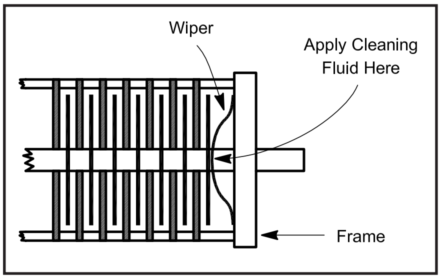

Fig 26.8 — Partial view of an air-dielectric variable capacitor. If the capacitor is noisy or erratic in operation, apply electronic cleaning fluid where the wiper contacts the rotor plates.

CLEANING

The only variety of common capacitor that can be repaired is the air-dielectric variable capacitor. Electrical connection to the moving plates is made through a spring-wiper arrangement (see **Fig 26.8**). Dirt normally builds on the contact area, and they need occasional cleaning. Before cleaning the wiper/contact, use gentle air pressure and a soft brush to remove all dust and dirt from the capacitor plates. Apply some electronic contact cleaning fluid. Do not lubricate the contact point. Rotate the shaft quickly several times to work in the fluid and establish contact. Use the cleaning fluid sparingly, and keep it off the plates except at the contact point.

Batteries and Tools

When working on equipment powered by a battery with a capacity of more than a few ampere-hours (Ah), take special care to avoid short circuits and always have a fuse or circuit-breaker in-line to the battery. If possible, fuse both the positive and negative connections. This is particularly important for vehicle batteries and mobile equipment. A short circuit can do thousands of dollars of damage to a vehicle's electrical power system in a matter of seconds! When working on mobile equipment, disconnect the battery's positive terminal or at least disconnect the circuit that powers the equipment by removing the fuse.

A tool that accidentally short-circuits the battery terminals can cause an instantaneous current flow of thousands of amps, often destroying both the battery and the tool and creating a significant fire and burn hazard.

REPLACEMENTS

Replacement capacitors should match the original in value, tolerance, dielectric, working voltage and temperature coefficient. Use only ac-rated capacitors for line service (capacitors connected directly to the ac line) to prevent fire hazards. If exact replacements are not available, substitutes may vary from the original part in the following respects: Bypass capacitors may vary from one to three times the capacitance of the original. Coupling capacitors may vary from one-half to twice the value of the original. Capacitance values in tuned circuits (especially filters) must be exact. (Even then, any replacement will probably require circuit realignment.)

If the same kind of capacitor is not available, use one with better dielectric characteristics. Do not substitute polarized capacitors for non-polarized parts. Capacitors with a higher working voltage may be used, although the capacitance of an electrolytic capacitor used significantly below its working voltage will usually increase with time.

The characteristics of each type of capacitor are discussed in the **Electrical Fundamentals** and **RF Techniques** chapters. Consider these characteristics if you're not using an exact replacement capacitor.

26.2.7 Inductors and Transformers

The most common inductor or transformer failure is a broken conductor. More rarely, a short circuit can occur across one or more turns of a coil. In an inductor, this changes the value. In a transformer, the turns ratio and resultant output voltage changes. In high-power circuits, excessive inductor current can generate enough heat to melt plastics used as coil forms.

Inductors may be checked for open circuit failure with an ohmmeter. In a good inductor, dc resistance rarely exceeds a few ohms. Shorted turns and other changes in inductance show only during alignment or inductance measurement.

The procedure for measurement of inductance with a dip meter is the same as that given for capacitance measurement, except that a capacitor of known value is used in the resonant circuit.

Replacement inductors must have the same inductance as the original, but that is only the first requirement. They must also carry the same current, withstand the same voltage and present nearly the same Q as the original part. Given the original as a pattern, the amateur can duplicate these qualities for many inductors. Note that inductors with ferrite or iron-powder cores are frequency sensitive, so the replacement must have the same core material.

If the coil is of simple construction, with the form and core undamaged, carefully count and write down the number of turns and their placement on the form. Also note how the coil leads are arranged and connected to the circuit. Then determine the wire size and insulation used. Wire diameter, insulation and turn spacing are critical to the current and voltage ratings of an inductor. (There is little hope of matching coil characteristics unless the wire is duplicated exactly in the new part.) Next, remove the old winding — be careful not to damage the form — and apply a new winding in its place. Be sure to dress all coil leads and connections in exactly the same manner as the original. Apply Q dope (a solution of polystyrene plastic) or a thin coating of plastic-based glue to hold the finished winding in place.

Follow the same procedure in cases where the form or core is damaged, except that a suitable replacement form or core (same dimensions and permeability) must be found.

Ready-made inductors may be used as replacements if the characteristics of the original and the replacement are known and compatible. Unfortunately, many inductors are poorly marked. If so, some comparisons, measurements and circuit analysis are usually necessary.

When selecting a replacement inductor, you can usually eliminate parts that bear no physical resemblance to the original part. This may seem odd, but the Q of an inductor depends on its physical dimensions and the permeability of the core material. Inductors of the same value, but of vastly different size or shape, will likely have a great difference in Q. The Q of the new inductor can be checked by installing it in the circuit, aligning the stage and performing the manufacturer's passband tests. Although this practice is all right in a pinch, it does not yield an accurate Q measurement. Methods to measure Q appear in the **Test Equipment and Measurements** chapter.

Once the replacement inductor is found, install it in the circuit. Duplicate the placement, orientation and wiring of the original. Ground-lead length and arrangement should not be changed. Isolation and magnetic shielding can be improved by replacing solenoid inductors with toroids. If you do, however, it is likely that many circuit adjustments will be needed to compensate for reduced coupling and mutual inductance. Alignment is usually required whenever a tuned-circuit component is replaced.

A transformer consists of two inductors that are magnetically coupled. Transformers are used to change voltage and current levels (this changes impedance also). Failure usually occurs as an open circuit or short circuit of one or more windings. Insulation failures can also occur that result in short circuits between windings or between windings and the core or case. It is also common for the insulated wire leads to develop cracks or abrasion where they come out of the case. This can be repaired easily by replacing the lead, or if the conducting wire strands are not burned or broken, by sliding an insulation sleeve over the wire to protect the insulation from further wear.

Amateur testing of power transformers is mostly limited to ohmmeter tests for open circuits and voltmeter checks of secondary voltage. Make sure that the power-line voltage is correct, then check the secondary voltage against that specified. There should be less than 10% difference between open-circuit and full-load secondary voltage. A test setup and procedure for evaluating power transformers is also provided in the **Power Sources** chapter.

Replacement transformers must match the original in voltage, volt-ampere (VA), duty cycle and operating-frequency ratings. They must also be compatible in size. (All transformer windings should be insulated for the full power supply voltage.)

When disconnecting a transformer for testing or repair, be sure to carefully record the color and connection for each of the transformer leads. In power transformers it is common for leads to be mostly one color but with a contrasting stripe or other pattern that can be overlooked. If in doubt, use tape or paper labels to note the connection for each lead. Recording transformer color codes and connections is a good use of the shack notebook.

26.2.8 Relays

Although relays have been replaced by semiconductor switching in low-power circuits, they are still used extensively in high-power Amateur Radio equipment for applications such as amplifier TR switching and in antenna systems or ac power control. Relay action may become sluggish. AC relays can buzz (with adjustment becoming impossible). A binding armature or weak springs can cause intermittent switching. Excessive use or hot switching ruins contacts and shortens relay life.

You can test relays with a voltmeter by measuring voltage across contacts (power on, in-circuit) or with an ohmmeter (out of circuit). Look for erratic readings across the contacts, open or short circuits at contacts or an open circuit at the coil. A visual inspection with a magnifying glass should show no oxidation or corrosion. Limited pitting is usually OK.

Most failures of simple relays can be repaired by a thorough cleaning. Clean the contacts and mechanical parts with a residue-free cleaner. Keep it away from the coil and plastic parts that may be damaged. Dry the contacts with lint-free paper, such as a business card; then burnish them with a smooth steel blade. Do not use a file to clean contacts because it will damage the contact surface.

Replacement relays should match or exceed the original specifications for voltage, current, switching time and stray impedance (impedance is significant in RF circuits only). Many relays used in transceivers are specially made for the manufacturer. Substitutes may not be available from any other source.

Before replacing a multi-contact relay, make a drawing of the relay, its position, the leads and their routings through the surrounding parts. This drawing allows you to complete the installation properly, even if you are distracted in the middle of the operation. (This is a good use of the shack notebook!)

26.2.9 Semiconductors

Testing diodes and transistors with the ohmmeter function of an analog VOM used to be the normal method. Today's inexpensive multimeters nearly always provide a forward and reverse junction voltage drop test function. This almost eliminates the need for resistance-based tests for functional troubleshooting with the attendant variability and dependence on meter circuits. However, it is occasionally useful to perform threshold and voltage-current testing to match components or troubleshoot a specialized circuit. In support of those tests, a short article "Diode and Transistor Test Circuits" containing test circuits and procedures for measuring leakage, gain, Zener point voltage and so forth is included on the CD-ROM accompanying this book. This section will focus on simple go/no-go testing.

DIODES

The primary function of a diode is to pass current in one direction only. They can be easily tested with an ohmmeter, and most multimeters have a diode junction test function built-in as well.

Signal or switching diodes — The most common diode in electronics equipment, signal diodes are used to convert ac to dc, to detect RF signals or to take the place of relays to switch ac or dc signals within a circuit. Signal diodes usually fail open, although shorted diodes are not rare.

Power rectifiers — Most equipment contains a power supply, so power rectifier diodes are the second-most common diodes in electronic circuitry. They usually fail shorted, blowing the power-supply fuse.

Other diodes — Zener diodes are made with a predictable reverse-breakdown voltage and are used as voltage regulators. Varactor diodes are specially made for use as voltage controlled variable capacitors. (Any semiconductor diode may be used as

a voltage-variable capacitance, but the value will not be as predictable as that of a varactor.) A Diac is a special-purpose diode that passes only pulses of current in each direction.

Diode testing — There are several basic tests for most diodes. First, is it a diode? Does it conduct in one direction and block current flow in the other? A simple resistance measurement is suitable for this test in most cases.

Diodes should be tested out of circuit. Disconnect one lead of the diode from the circuit, then perform the test. We can also test diodes by measuring the voltage drop across the diode junction while the diode is conducting.

A functioning diode will show high resistance in one direction and low resistance in the other. A DMM with a diode-test function is the best instrument to use. If using an analog meter, make sure more than 0.7 V and less than 1.5 V is used to measure resistance. Use the highest resistance scale of the meter that gives a reading of less than full-scale. Check a known-good diode to determine the meter polarity if there is any question. Compare the forward and reverse resistance readings for a known-good diode to those of the diode being tested to determine whether the diode is good.

Diode junction forward voltage drops are measured by a multimeter's diode test function. Silicon junctions usually show about 0.6 V at typical test current levels, while germanium is typically 0.2 V. Junction voltage drop increases with current flow.

Multimeters measure the junction resistances at low voltage and are not useful for testing Zener diodes. A good Zener diode will not conduct in the reverse direction at voltages below its rating. See the CD-ROM article mentioned at the beginning of this section for procedures and a circuit to determine Zener diode performance.

Replacement diodes — When a diode fails, check associated components as well. Replacement rectifier diodes should have the same current and peak inverse voltage (PIV) as the original. Series diode combinations are often used in high-voltage rectifiers. (The resistor and capacitor networks used to distribute the voltage equally among the diodes are no longer required for new rectifiers but should be retained for older parts. See the **Power Sources** chapter for more information.)

Switching diodes may be replaced with diodes that have equal or greater current ratings and a PIV greater than twice the peak-to-peak voltage encountered in the circuit. Switching time requirements are not critical except in RF, logic and some keying circuits. Logic circuits may require exact replacements to assure compatible switching speeds and load characteristics. RF switching diodes used near resonant circuits must have exact replacements as the diode resistance and capacitance will affect the tuned circuit.

Voltage and capacitance characteristics must be considered when replacing varactor diodes. Once again, exact replacements are best. Zener diodes should be replaced with parts having the same Zener voltage and equal or higher power rating, and equal or lower tolerance. Check the associated current-limiting resistor when replacing a Zener diode.

BIPOLAR TRANSISTORS

Transistor failures occur as an open junction, a shorted junction, excess leakage or a change in amplification performance. Most transistor failure is catastrophic. A transistor that has no leakage and amplifies at dc or audio frequencies will usually perform well over its design range. For this reason, transistor tests need not be performed at the planned operating frequency. Tests are made at dc or a low frequency (usually 1000 Hz). The circuit under repair is the best test of a potential replacement part. Swapping in a replacement transistor in a failed circuit will often result in a cure.

A simple and reliable test of bipolar transistors can be performed with the transistor in a circuit and the power on. It requires a test lead, a 10 kΩ resistor and a voltmeter. Connect the voltmeter across the emitter/collector leads and read the voltage. Then use the test lead to connect the base and emitter (**Fig 26.9A**). Under these conditions, conduction of a good transistor will be cut off and the meter should show nearly the entire supply voltage across the emitter/collector leads. Next, remove the clip lead and connect the 10 kΩ resistor from the base to the collector. This should bias the transistor into conduction and the emitter/collector voltage should drop (Fig 26.9B). (This test indicates transistor response to changes in bias voltage.)

Transistors can be tested (out of circuit) with an ohmmeter in the same manner as diodes or a multimeter with a transistor test function can be used. Before using the ohmmeter-transistor circuit, look up the device characteristics before testing and consider possible consequences of testing the transistor in this way. Limit junction current to 1 to 5 mA for small-signal transistors. Transistor destruction or inaccurate measurements may result from careless testing.

The reverse-to-forward resistance ratio for good transistors may vary from 30:1 to better than 1000:1. Germanium transistors — still occasionally encountered — sometimes show high leakage when tested with an ohmmeter. Bipolar transistor leakage may be specified from the collector to the base, emitter to base or emitter to collector (with the junction reverse biased in all cases). The specification may be identified as I_{cbo}, I_{bo}, collector cutoff current or collector leakage for the base-collector junction, I_{ebo}, and so on for other junctions. Leakage current increases with junction temperature. (See the **Analog Basics** chapter for definitions of these and other transistor parameters.)

While these simple test circuits will identify most transistor problems, RF devices should be tested at RF. Most component manufacturers include a test-circuit schematic on the data sheet. The test circuit is usually an RF amplifier that operates near

Cross-Reference Replacement Semiconductors

Semiconductors from older equipment, even ICs, may be available as a cross-reference generic replacement. The primary source for these devices is NTE Electronics (**www.nteinc.com**). Enter the part number of the device you are trying to replace in the "Cross-Reference" window. NTE also supplies cross-referenced replacements for ECG part numbers which were the original generic replacement parts.

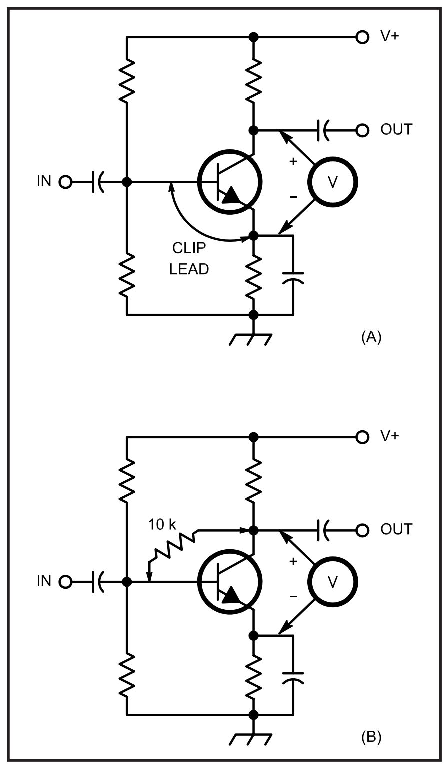

Fig 26.9 — An in-circuit semiconductor test with a clip lead, resistor and voltmeter. The meter should read V+ at (A). During test (B) the meter should show a decrease in voltage, ranging from a slight variation down to a few millivolts. It will typically cut the voltage to about half of its initial value.

the high end of the device frequency range. If testing at RF is not possible, substitution of a known-good device is required.

Semiconductor failure is sometimes the result of environmental conditions. Open junctions, excess leakage (except with germanium transistors) and changes in amplification performance result from overload or excessive current.

Shorted junctions (low resistance in both directions) are usually caused by voltage spikes. Electrostatic discharge (ESD) or transients from lightning can destroy a semiconductor in microseconds.

Transistors rarely fail without an external cause. Check the surrounding parts for the cause of the transistor's demise, and correct the problem before installing a replacement.

JFETs

Junction FETs can be tested with a multimeter's diode junction test function in much the same way as bipolar transistors (see text and **Fig 26.10**). Reverse leakage should be several megohms or more. Forward resistance should be 500 to 1000 Ω if measured with an analog meter.

MOSFETs

Small-signal MOS (metal-oxide semiconductor) layers are extremely fragile. Normal body static is enough to damage them. Even gate protected (a diode is placed across the MOS layer to clamp voltage) MOSFETs may be destroyed by a few volts of static electricity. MOSFETs used for power circuits and RF amplifiers are much more resistant to damage. The manufacturer's sheet will specify any special static-protection measures that are required. (See the **Construction Techniques** chapter for more information about managing static at the workbench.)

When testing small MOSFETs make sure the power is off, capacitors discharged and the leads are shorted together before installing or removing it from a circuit. Use a voltmeter to be sure the chassis is near ground potential, then touch the chassis before and during MOSFET installation and removal. This assures that there is no difference of potential between your body, the chassis and the MOSFET leads. Ground the soldering-iron tip with a clip lead when soldering MOS devices. The FET source should be the first lead connected to and the last disconnected from a circuit. The insulating layers in MOSFETs prevent testing with an ohmmeter. Substitution is the only practical means for amateur testing of MOSFETs.

FET CONSIDERATIONS

Replacement FETs should be of the same type as the original part: JFET or MOSFET, P-channel or N-channel, enhancement or depletion. Consider the breakdown voltage required by the circuit. The breakdown voltage should be at least two to four times the power-supply and signal voltages in amplifiers. Allow for transients of 10 times the line voltage in power supplies. Breakdown voltages are usually specified as $V_{(BR)GSS}$ or $V_{(BR)GDO}$.

The gate-voltage specification gives the gate voltage required to cut off or initiate channel current (depending on the mode of operation). Gate voltages are usually listed as $V_{GS(OFF)}$, V_p (pinch off), V_{TH} (threshold) or $I_{D(ON)}$ or I_{TH}.

Dual-gate MOSFET characteristics are more complicated because of the interaction of the two gates. Cutoff voltage, breakdown voltage and gate leakage are the important traits of each gate.

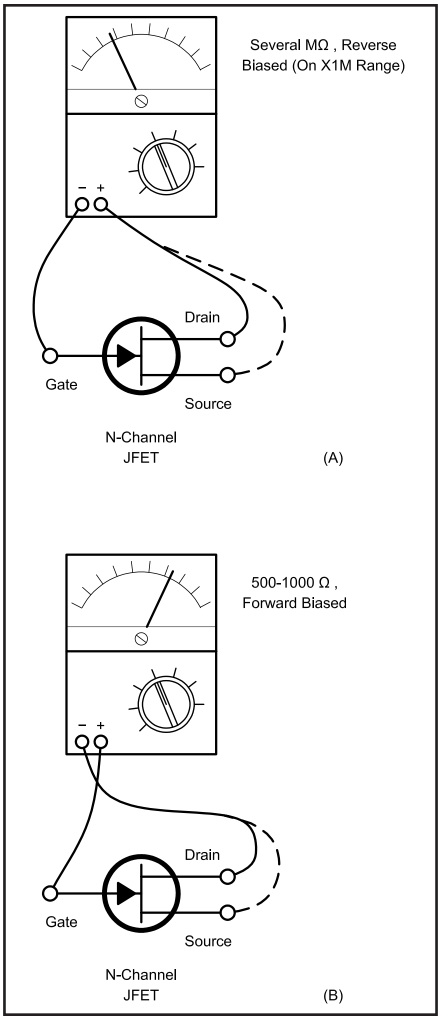

Fig 26.10 — Ohmmeter tests of a JFET. The junction is reverse biased at A and forward biased at B. (Analog meters are shown for convenience of illustration.)

INTEGRATED CIRCUITS

The basics of integrated circuits are covered in earlier chapters of this book. Amateurs seldom have the sophisticated equipment required to test ICs. Even a multi-channel oscilloscope can view only their simplest functions. We must be content to check every other possible cause, and only then assume that the problem lies with an IC. Experienced troubleshooters will tell you that — most of the time anyway — if a defective circuit uses an IC, it is the IC that is bad.

Linear ICs — There are two major classes of ICs: linear and digital. Linear ICs are best replaced with identical units. Original equipment manufacturers are the best source of a replacement; they are the only source with a reason to stockpile obsolete or custom-made items. If substitution of an IC is unavoidable, first try the cross-reference website of NTE mentioned in the sidebar. You can also look in manufacturers' websites and compare pinouts and other specifications.

Digital ICs — It is usually not a good idea to substitute digital devices. While it may be okay to substitute an AB74LS00YZ from one manufacturer with a CD74LS00WX from a different manufacturer, you will usually not be able to replace an LS (low-power Schottky) device with an S (Schottky), C (CMOS) or any of a number of other families. The different families all have different speed, current-consumption, input and output characteristics. You would have to analyze the circuit to determine if you could substitute one type for another.

SEMICONDUCTOR SUBSTITUTION

In all cases try to obtain exact replacement semiconductors. Specifications vary slightly from one manufacturer to the next. Cross-reference equivalents such as NTE (**www.nteinc.com**) are useful, but not guaranteed to be an exact replacement. Before using an equivalent, check the specifications against those for the original part. When choosing a replacement, consider:

- Is it a PNP or an NPN?
- What are the operating frequency and input/output capacitance?
- How much power can it dissipate (often less than Vmax × Imax)?
- Will it fit the original socket or pad layout?
- Are there unusual circuit demands (low noise and so on)?
- What is the frequency of operation?

Remember that cross-reference equivalents are not guaranteed to work in every application. In cases where an absolutely exact replacement is required for an obsolete part, Rochester Electronics (**www.rocelec.com**) or 4 Star Electronics (**www.4starelectronics.com**) maintain extensive stocks, although the cost is likely to be rather high.

There may be cases where two dissimilar

devices have the same part number, so it pays to compare the listed replacement specifications with the intended use. If the book says to use a diode in place of an RF transistor, it isn't going to work! Derate power specifications, as recommended by the manufacturer, for high-temperature operation.

26.2.10 Tubes

The most common tube failures in amateur service are caused by cathode depletion and gas contamination. Whenever a tube is operated, the coating on the cathode loses some of its ability to produce electrons. It is time to replace the tube when electron production (cathode current, I_c) falls to 50 to 60% of that exhibited by a new tube.

Gas contamination in a tube can often be identified easily because there may be a greenish or whitish-purple glow between the elements during operation. (A faint deep-purple glow is normal in most tubes.) The gas reduces tube resistance and leads to runaway plate current evidenced by a red glow from the anode, interelectrode arcing or a blown power supply fuse. Less common tube failures include an open filament, broken envelope and inter-electrode shorts.

The best test of a tube is to substitute a new one. Another alternative is a tube tester; these are sometimes available at hamfests or through antique radio or audiophile groups. You can also do some limited tests with an ohmmeter. Tube tests should be made out of circuit so circuit resistance does not confuse the results.

Use an ohmmeter to check for an open filament (remove the tube from the circuit first). A broken envelope is visually obvious, although a cracked envelope may appear as a gassy tube. Interelectrode shorts are evident during voltage checks on the operating stage. Any two elements that show the same voltage are probably shorted. (Remember that some inter-electrode shorts, such as the cathode-suppressor grid, are normal.)

Generally, a tube may be replaced with another that has the same type number. Compare the data sheets of similar tubes to assess their compatibility. Consider the base configuration and pinout, inter-electrode capacitances (a small variation is okay except for tubes in oscillator service), dissipated power ratings of the plate and screen grid and current limitations (both peak and average). For example, the 6146A may usually be replaced with a 6146B (heavy duty), but not vice versa.

In some cases, minor type-number differences signify differences in filament voltages, or even base styles, so check all specifications before making a replacement. (Even tubes of the same model number, prefix and suffix vary slightly, in some respects, from one supplier to the next.)

26.3 Getting Started

INSTINCTIVE OR SYSTEMATIC

A systematic approach to troubleshooting uses a defined process to analyze and isolate the problem. An instinctive approach relies on troubleshooting experience to guide you in selecting which circuits to test and which tests to perform.

When instinct is based on experience, searching by instinct may be the fastest procedure. If your instinct is correct, repair time and effort may be reduced substantially. As experience and confidence grow, the merits of the instinctive approach grow with them. However, inexperienced technicians who choose this approach are at the mercy of chance.

A systematic approach is a disciplined procedure that allows us to tackle problems in unfamiliar equipment with a reasonable hope of success. The systematic approach is usually chosen by beginning troubleshooters.

26.3.1 The Systematic Approach

Armed with a collection of test equipment, you might be tempted to immediately dig in and start looking for the problem. While it is sometimes obvious what piece of equipment or subassembly inside equipment is at fault, the many connections that make up nearly all ham stations today make it far more effective to begin troubleshooting by looking at the problem from the system perspective. By *system*, we mean more than one piece of equipment or subassemblies connected together — nothing fancier than that.

Amateur stations are full of systems: a digital mode system is made up of a radio, power supply, and PC. An antenna system consists of the antenna tuner, feed line, and antenna. Inside a radio there is a system made up of the power circuits, receiver, transmitter, control panel, and transmit-receive switching circuits. Connections between parts of the system need not be cables; wireless data links can also be part of a system.

In general, it's best to approach any problem — even the supposedly obvious problems — from the perspective of the system it affects. The first step is to determine the system with the smallest number of components that exhibits the problem. Then you can start looking for the problem in one of those components or the connection between them. We'll start with an example to illustrate the process.

Problem — After a year of trouble-free operation, when you transmit with more than 50 W of output power using PSK31, other stations now report lots of distortion products around your signal on the waterfall display, even though the ALC is not active at all and no software level settings have been changed. This could be RF interference, a problem with the digital interface between the PC and the radio, settings in the PC, settings in the radio, a bad connection...there are lots of possibilities.

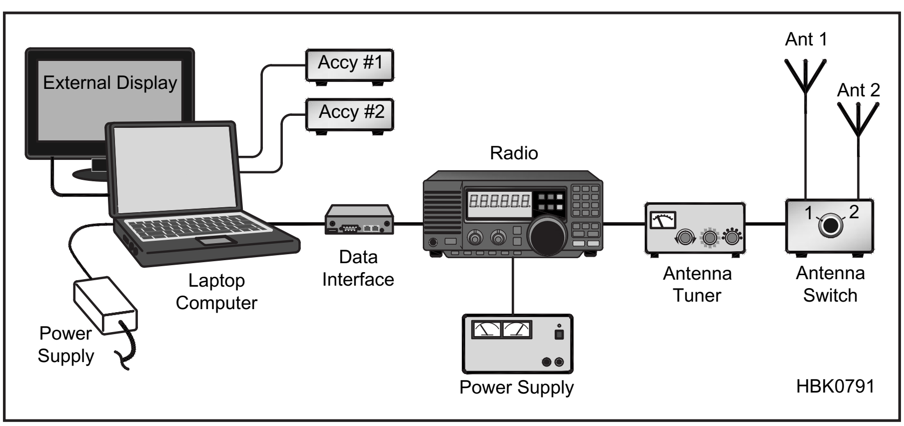

Fig 26.11 — The complete system of radio and power supply, data interface, laptop PC with a couple of accessories and power supply, antenna tuner, antenna switch, antenna 1 and 2, and interconnecting cables.

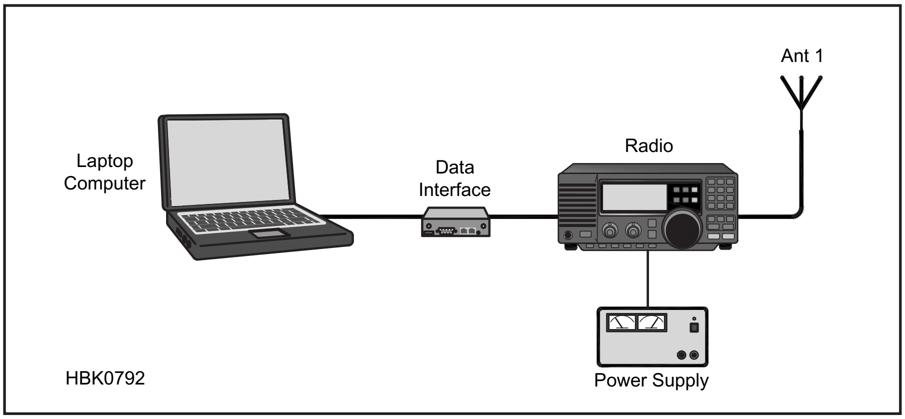

Fig 26.12 — The minimum system of radio and power supply, digital interface, laptop on battery power, antenna 1, and interconnecting cables.

Read the Manual!

Your equipment may be working as designed. Many electronic "problems" are caused by a switch or control in the wrong position, a misconfigured menu item, or a unit that is being asked to do something it was not designed to do. Before you open up your equipment for major surgery, make sure you are using it correctly. Most user's manuals have a procedure for setting up the equipment initially and for performing partial and full resets of microprocessor-controlled gear.

Get a pad of paper and sketch out the system that is exhibiting the problem, such as in **Fig 26.11**. Write down what the symptom(s) is(are) and the conditions under which they occur. Fig 26.11 shows that you have a system that has a lot of parts involved, including the interconnecting cables. Let's simplify that system! For this type of problem, it would be very helpful to have a friend available to listen on the air as you troubleshoot. To find the minimum system, start by removing any accessories that aren't being used from the radio and PC and trying to reproduce the problem, writing down each step and noting whether the problem changed. Not only will you simplify the problem but in the process you will have an excellent opportunity to inspect and check connections and configurations — perhaps even discovering the problem!

Let's say that the distortion persists with the mouse and external display disconnected and the laptop running from its internal battery. Then you were able to remove the antenna tuner and antenna switch, manually attaching just one antenna to the radio at a time, and found that the problem only occurred when using antenna 1. Removing any other part of the system makes it non-functional, so you have found the minimum system with the problem as shown in **Fig 26.12**.

Now it's time to start making small changes in the minimum system to observe the effect, again taking notes as you go. Changing the microphone gain a little bit up and down has hardly any effect. Changing the PC sound card output audio level a little bit also has hardly any effect. Reducing RF output power a little bit has a *big* effect: as power is reduced, so are the distortion products. Below 35 W, the problem was completely gone! This is an important clue, dutifully recorded on the pad of paper. Replacing antenna 1 with a dummy load had a similar effect — the problem disappeared according to your friend, who lives close enough to hear the weak signal leaking out of your greatly reduced antenna system. Putting antenna 1 back on the radio causes the problem to come back above 35 W, too.

The behavior of the problem points strongly to RF being picked up by a cable in your minimum system and interfering with the low-level digital audio. It's time for a close inspection of each remaining cable. Removing the radio's microphone connector shell and checking the wires inside didn't turn up anything — all of the connections were intact and only touching what they were supposed to touch. Looking at the cable between the digital interface and the sound card, though, you see that the shield of the cable at the PC end is badly frayed and barely making contact at all! In a few minutes, you've trimmed and re-soldered the cable, plugging it back into the PC. Testing even at full power output shows no distortion products on either antenna.

You fixed the problem by finding the minimum system and then inspecting one thing at a time until the root cause was found and eliminated.

What if the root cause didn't appear when you checked the cables? Then you would have to continue to test the system at the interfaces where the system components are connected together. You could measure signal levels with a sensitive voltmeter. You could add ferrite beads or cores on cables that might be picking up RF. You could check to see if the radio's power supply output is stable and clean as the transmitter power increases.

Another strategy would be to substitute known good components, one at a time, and see if the problem changes or disappears: You might swap in a different data interface. You could change the cables. Try a different power supply or radio or laptop.

Most systematic testing combines direct testing or inspection and a process of substitution. The goal is to either find the root cause or find the system component in which the root cause is hiding. Once you have a system component identified as the culprit, treat the component as a system itself and start the process all over again. Eventually, you'll find the problem.

Here are some guidelines to systematic troubleshooting in the ham shack:

1. Take the time to define and understand the system exhibiting the problem.
2. Remove system components one at a time.
3. Verify that the problem still exists. If not, restore that component.
4. Continue to remove components and test until the minimum system exhibiting the problem has been reached.
5. Inspect what is happening at each interface between system components by testing or substitution. In the example, you inspected the cables connecting the radio and other system components.
6. If a problem is identified, correct it and re-test.
7. Otherwise, continue to test or substitute each system component until the root cause has been identified or isolated to one component.
8. Treat that component as a new system and return to step 1.

Systematically reducing the number of components and testing each interface between them is almost always the fastest way to determine where the problem's root cause really lies. You may be a lucky guesser and sometimes a little plume of smoke is a dead giveaway, but in the long run, the system approach will save you time and money.

26.3.2 Assessing the Symptoms

An important part of the troubleshooting process is a careful definition of just what the symptoms of the problem really are. It is important to note exactly how the

problem manifests itself and the conditions under which the problem occurs. Avoid vague descriptions such as "broken" and "not working." Train yourself to use precise descriptions such as "relay fails to activate" or "no speaker output."

Ask yourself these questions:

1. What functions of the equipment do not work as they should; what does not work at all?

2. What kind of performance can you realistically expect?

3. Has the trouble occurred in the past? (Keep a record of troubles and maintenance in the owner's manual, shack notebook or log book.)

Write down the answers to the questions. The information will help with your work, and it may help service personnel if their advice or professional service is required.

Question your assumptions and verify what you think you know. Are you *sure* that power supply output is OK under all conditions? Did you actually confirm that there is continuity at every position of the antenna switch? If there is any doubt, make a confirming measurement or inspection. Countless hours have been wasted because of unjustified assumptions!

Intermittent problems are generally harder to track down, so try to note the conditions under which the problem occurs — those are often important clues.

Troubleshooting is a good reason to do regular maintenance. Not only will you have fewer problems, but when something is just a little off or out of place, you are much likelier to notice it. Learn to listen to the little voice in your head noting something out of the ordinary. Don't discount the wild cards that occasionally cause problems.

Occasionally step away from the workbench and relax. Take a walk. Your mind will continue to think about the problem and you may surprise yourself when you sit back down to work!

If you can bounce ideas off a friend, try explaining the problem and letting the friend ask you questions. It's common for someone else with a different perspective to ask questions you haven't thought of.

Newly Constructed Equipment

What if you built a piece of equipment and it doesn't work? In most repair work, the troubleshooter is aided by the knowledge that the circuit once worked so that it is only necessary to find and replace the faulty part(s). This is not the case with newly constructed equipment.

Repair of equipment with no working history is a special, and difficult, case. You may be dealing with a defective component, construction error or even a faulty design. Carefully checking for these defects can save you hours. This is a good reason to test homebrew equipment at each possible step and on a section-by-section basis, if possible. In that way, you'll know more about what does work if the completed project has a problem.

26.3.3 External Inspection

Inspection is the easiest part of troubleshooting to do and careful, detailed inspection will often find the problem or a clue that leads to it. Make sure you have some paper to keep notes on as you go so when something occurs to you it can be recorded.

Try the easy things first. If you are able to solve the problem by replacing a fuse or reconnecting a loose cable, you might be able to avoid a lot of effort. Many experienced technicians have spent hours troubleshooting a piece of equipment only to learn the hard way that the on/off switch was set to OFF or the squelch control was set too high, or that they were not using the equipment properly.

Next, make sure that equipment is plugged in, that the ac outlet does indeed have power, that the equipment is switched on and that all of the fuses are good. If the equipment uses batteries or an external power supply, make sure they supply the right voltage under load.

Check that all wires, cables and accessories are working and plugged into the right connectors or jacks. In a system of components it is often difficult to be sure which component or subsystem is bad. Your transmitter may not work on SSB because the transmitter is bad, but it could also be a bad microphone.

Connector faults or misconnections are common. Consider them prime suspects in your troubleshooting detective work. Do a thorough inspection of the connections. Is the antenna connected? How about the speaker, fuses and TR switch? Are transistors and ICs firmly seated in their sockets? Are all interconnection cables sound and securely connected? Are any pins bent or is a connector inserted improperly? Many of these problems are obvious to the eye, so look around carefully.

While you are performing your inspection, don't forget to use all of your senses. Do you smell anything burnt or overheated? Is something leaking electrolyte or oil? Perhaps a component or connector looks overheated and discolored. Is mounting hardware secure?

Once you're done with your inspection, retest the equipment to be sure the problem is still there or note if it has changed in some way.

26.4 Inside the Equipment

At this point, you've determined that a specific piece of equipment has a problem. A visual inspection of all the operating controls and connections hasn't turned up anything, but the problem is still there. It is time to really dig in, take it apart, and fix it!

26.4.1 Documentation

In order to test any piece of equipment, you'll probably need at least a user's manual. If at all possible, locate a schematic diagram and service manual. It is possible to troubleshoot without a service manual, but a schematic is almost indispensable.

The original equipment manufacturer is the best source of a manual or schematic. However, many old manufacturers have gone out of business. Several sources of equipment manuals can be located by a web search or from one of the *QST* vendors that sell equipment needs. In addition K4XL's Boat Anchor Manual Archive (**www2.faculty.sbc.edu/kgrimm/boatanchor**) has hundreds of freely downloadable electronic copies of equipment manuals. If there is a user's group or email list associated with your equipment, a request to the group may turn up a manual and maybe even troubleshooting assistance.

If all else fails, you can sometimes reverse engineer a simple circuit by tracing wiring paths and identifying components to draw your own schematic. By downloading datasheets for the active devices used in the circuit, the pin-out diagrams and applications notes will sometimes be enough to help you understand and troubleshoot the circuit.

THE BLOCK DIAGRAM

An important part of the documentation, the block diagram is a road map. It shows the signal paths for each circuit function. These paths may run together, cross occasionally or not at all. Those blocks that are not in the paths of faulty functions can be eliminated

as suspects. Sometimes the symptoms point to a single block and no further search is necessary. In cases where more than one block is suspect, several approaches may be used. Each requires testing a block or stage.

26.4.2 Disassembly

This seemingly simple step can trap the unwary technician. Most experienced service technicians can tell you the tale of the equipment they took apart and were unable to easily put back together. Don't let it happen to you.

Take photos and lots of notes about the way you take it apart. Take notes about each component you remove. Take a photo or make a sketch of complicated mechanical assemblies before disassembly and then record how you disassembled them. It is particularly important to record the position of shields and ground straps.

Write down the order in which you do things, color codes, part placements, cable routings, hardware notes, and anything else you think you might need to be able to reassemble the equipment weeks from now when the back-ordered part comes in.

Put all of the screws and mounting hardware in one place. A plastic jar with a lid works well; if you drop it the plastic is not apt to break and the lid will keep all the parts from flying around the work area (you will never find them all). It may pay to have a separate labeled container for each subsystem. Paper envelopes and muffin pans also work well.

26.4.3 Internal Inspection

Many service problems are visible, if you look for them carefully. Many a technician has spent hours tracking down a failure, only to find a bad solder joint or burned component that would have been spotted in careful inspection of the printed-circuit board. Internal inspections are just as important as external inspections.

It is time consuming, but you really need to look at every connector, every wire, every solder joint and every component. A low power magnifying glass or head-mounted magnifier enables you to quickly scan the equipment to look for problems. A connector may have loosened, resulting in an open circuit. You may spot broken wires or see a bad solder joint. Flexing the printed-circuit board or tugging on components a bit while looking at their solder joints will often locate a defective solder job. Look for scorched components.

Make sure all of the screws securing the printed-circuit board are tight and making good electrical contact. Check for loose screws on chassis-mounted connectors. (Do not tighten any electrical or mechanical adjusting screws or tuning controls, however!) See if you can find evidence of previous repair jobs; these may not have been done properly. Make sure that ICs are firmly seated in sockets if they are used. Look for pins folded underneath the IC rather than inserted into the socket. If you are troubleshooting a newly constructed circuit, make sure each part is of the correct value or type number and is installed correctly.

POWER SUPPLIES

If your careful inspection doesn't reveal anything, it is time to apply power to the unit under test and continue the process. Observe all safety precautions while troubleshooting equipment. There are voltages inside some equipment that can kill you. If you are not qualified to work safely with the voltages and conditions inside of the equipment, do not proceed. See Table 26.1 and the **Safety** chapter.

You may be able to save quite a bit of time if you test the power supply right away. If the power supply is not working at all or not working properly, no other circuit in the equipment can be expected to work properly either. Once the power supply has either been determined to be OK or repaired, you can proceed to other parts of the equipment. Power supply diagnosis is discussed in detail later in this chapter.

With power applied to the equipment, listen for arcs and look and smell for smoke or overheated components. If no problems are apparent, you can move on to testing the various parts of the circuit. For tube equipment, you may want to begin with ac power applied at a reduced voltage as described in the sections on repair of vintage equipment.

26.4.4 Signal Tracing and Signal Injection

There are two common systematic approaches to troubleshooting radio equipment at the block level. The first is signal tracing; the second is signal injection. The two techniques are very similar. Differences in test equipment and the circuit under test determine which method is best in a given situation. They can often be combined.

Both of these approaches are used on equipment that is designed to operate on a

Knowing When to Quit

It is common for experienced repair techs to be given "basket cases" — equipment that the original troubleshooter disassembled but then couldn't reassemble for whatever reason or couldn't find the problem. One of the most important decisions in the troubleshooting process is knowing when to quit. That is, realizing that you are about to go beyond your skills or understanding of the equipment.

If you proceed past this point, the chances of a successful outcome go down pretty quickly. It's far better to ask for help, work with a more knowledgeable friend, or carefully re-assemble the equipment and take it to a repair tech. Don't let your equipment wind up as a box full of partially connected pieces and mounting hardware under the table at the hamfest with a sign that says, "Couldn't fix — make offer!"

Block-Level Testing for DSP and SDR

More and more functions of today's radio equipment are implemented by microprocessor-based digital signal processing up to and including full SDR with direct digitization of RF signals very close to the antenna input. A look at the PC boards of such a radio show a few large, many-leaded ICs surrounded by control and interface components, power supply circuits, filtering, and transmitter power amplifiers. The individual stages of the classic superheterodyne architecture are nowhere to be seen. How do you troubleshoot such a radio?

Start with the same basic approach as for an older radio — begin at the input or output and work your way towards the "other end" of the radio. In a DSP-based radio however, you'll rapidly encounter the point at which the signal "goes digital" and disappears into the microprocessor or an analog/digital converter. Jump to the point where the signal returns to analog form on the "other side" of the microprocessor (or PC in the case of most SDR equipment) and resume testing. In this way you can simply treat the microprocessor as one very large stage in the radio. If the problem turns out to be in the surrounding circuitry or in the interface between a PC and the RF circuits, you can troubleshoot it as you would any other piece of equipment.

If the problem turns out to be in the microprocessor or analog/digital converter, in all probability you will have to get a replacement board from the manufacturer. It is possible to replace the converter or processor (if you can obtain the pre-programmed part) but most manufacturers treat the entire circuit board as the lowest-level replaceable component. This makes repair more expensive (or impossible if no replacements are available) but the positive tradeoff is that the microprocessors rarely fail by themselves, resulting in fewer repairs being required in the first place.

signal (RF or audio or data) in a sequence of steps. A transceiver based on the superheterodyne architecture is probably the best example of this type of equipment in the ham shack. Audio equipment is also built this way. More information about the signal injector and signal sources appears in "Some Basics of Equipment Servicing," from February 1982 *QST* (Feedback, May 1982).

Newer equipment that incorporates DSP and specialized or proprietary ICs is much less amenable to stage-by-stage testing techniques. (See the sidebar "Block-Level Testing for DSP and SDR") Nevertheless, the techniques of signal tracing and signal injection are still useful where the signal path is accessible to the troubleshooter.

SIGNAL TRACING

In signal tracing, start at the beginning of a circuit or system and follow the signal through to the end. When you find the signal at the input to a specific stage, but not at the output, you have located the defective stage. You can then measure voltages and perform other tests on that stage to locate the specific failure. This is much faster than testing every component in the unit to determine which is bad.

It is sometimes possible to use over-the-air signals in signal tracing, in a receiver for example. However, if a good signal generator is available, it is best to use it as the signal source. A modulated signal source is best.

Signal tracing is suitable for most types of troubleshooting of receivers and analog amplifiers. Signal tracing is the best way to check transmitters because all of the necessary signals are present in the transmitter by design. Most signal generators cannot supply the wide range of signal levels required to test a transmitter.

Equipment

A voltmeter with an RF probe is the most common instrument used for signal tracing. Low-level signals cannot be measured accurately with this instrument. Signals that do not exceed the junction drop of the diode in the probe will not register at all, but the presence, or absence, of larger signals can be observed.

A dedicated signal tracer can also be used. It is essentially an audio amplifier. (See this book's CD-ROM for a project to build your own signal tracer.) An experienced technician can usually judge the level and distortion of the signal by ear. You cannot use a dedicated signal tracer to follow a signal that is not amplitude modulated (single sideband is a form of AM). A signal tracer is not suitable for tracing CW signals, FM signals or oscillators. To trace these, you will have to use a voltmeter and RF probe or an oscilloscope.

An oscilloscope is the most versatile signal tracer. It offers high input impedance, variable sensitivity, and a constant display of the traced waveform. If the oscilloscope has sufficient bandwidth, RF signals can be observed directly. Alternatively, a demodulator probe can be used to show demodulated RF signals on a low-bandwidth oscilloscope. Dual-trace scopes can simultaneously display the waveforms, including their phase relationship, present at the input and output of a circuit.

Procedure

First, make sure that the circuit under test and test instruments are isolated from the ac line by internal transformers, an isolation transformer, or operate from battery power. Set the signal source to an appropriate level and frequency for the unit you are testing. For a receiver, a signal of about 100 µV should be plenty. For other circuits, use the schematic, an analysis of circuit function and your own good judgment to set the signal level.

In signal tracing, start at the beginning and work toward the end of the signal path. Switch on power to the test circuit and connect the signal-source output to the test-circuit input. Place the tracer instrument at the circuit input and ensure that the test signal is present. Observe the characteristics of the signal if you are using a scope (see **Fig 26.13**). Compare the detected signal to the source signal during tracing.

Move the test instrument to the output of the next stage and observe the signal. Signal level should increase in amplifier stages and may decrease slightly in other stages. The signal will not be present at the output of a dead stage.

Low-impedance test points may not provide sufficient signal to drive a high-impedance

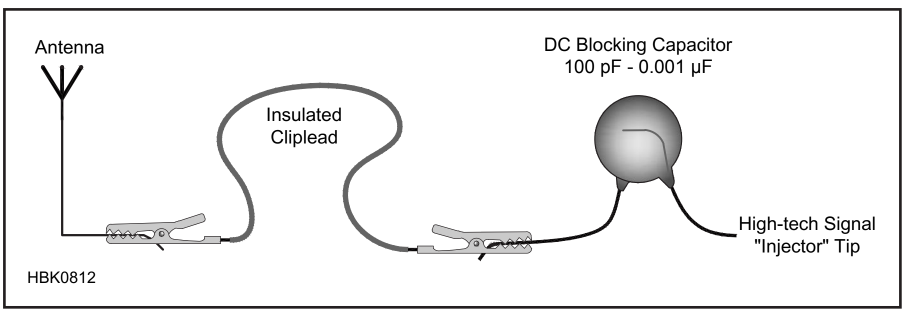

Fig 26.14 — A simple signal injector that uses an antenna to pick up signals to be applied to the circuit under test. [Courtesy Elecraft, www.elecraft.com]

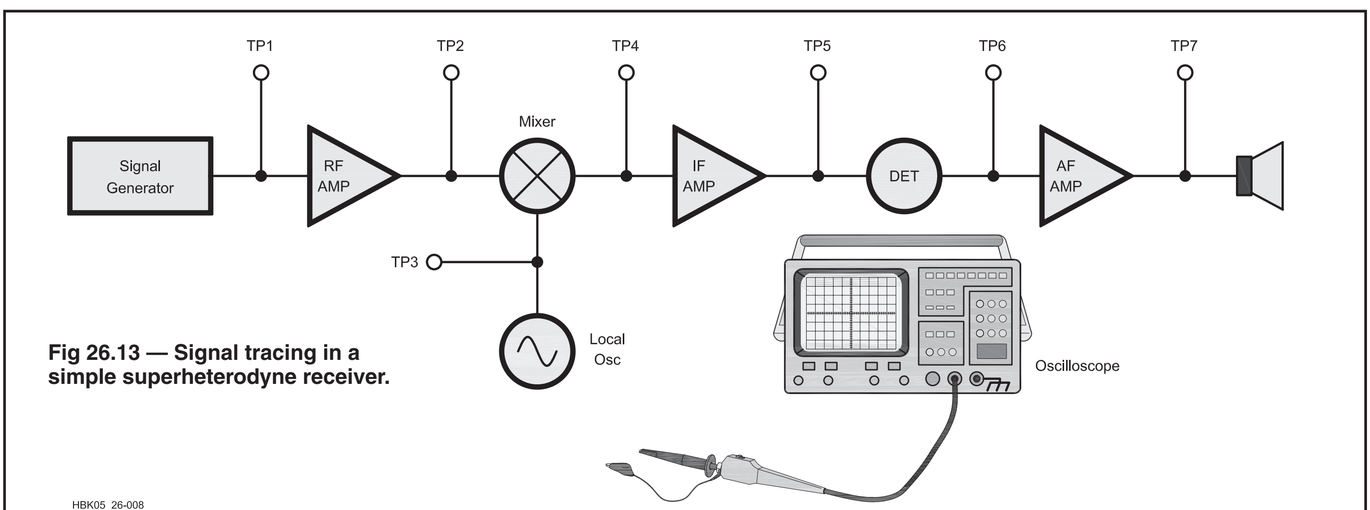

Fig 26.13 — Signal tracing in a simple superheterodyne receiver.

signal tracer, so tracer sensitivity is important. Also, in some circuits the output level appears low where there is an impedance change from input to output of a stage. For example, in a properly-working common-collector (emitter follower) circuit, the input (high-impedance) and output (low-impedance) signals are in phase and have roughly equal voltages. The voltages at TP1 and TP2 are approximately equal and in phase.

There are two signals — the test signal and the local oscillator signal — present in a mixer stage. Loss of either one will result in no output from the mixer stage. Switch the signal source on and off repeatedly to make sure that the test instrument reading varies (it need not disappear) with source switching.

SIGNAL INJECTION

Signal injection is a good choice for receiver troubleshooting because the receiver already has a detector as part of the design. If the detector is working or a suitable detector is devised (see the signal tracing section), a test signal can be injected at different points in the equipment until the faulty stage is discovered.

Equipment

Most of the time, your signal injector will be a signal generator. There are other injectors available, some of which are square-wave audio oscillators rich in RF harmonics (see Fig 26.5). These simple injectors do have their limits because you can't vary their output level or determine their frequency. They are still useful, though, because most circuit failures are caused by a stage that is completely dead.

Consider the signal level at the test point when choosing an instrument. The signal source used for injection must be able to supply appropriate frequencies and levels for each stage to be tested. For example, a typical superheterodyne receiver requires AF, IF and RF signals that vary from 6 V at AF, to 200 µV at RF. Each conversion stage used in a receiver requires a different IF from the signal source. When testing the signal path of an AM radio, such as a broadcast receiver, you'll need a modulated RF signal before the detector stage. Use an unmodulated RF signal to simulate the local oscillator.

The simple test circuit of **Fig 26.14** can be used as a quick-and-dirty signal injector for RF stages in a receiver. The antenna can be anything that will receive a signal at the stage's frequency of operation.

Procedure

If an external detector is required, set it to the proper level and connect it to the test circuit. Set the signal source for AF, and inject a signal directly into the signal detector to test operation of the injector and detector. Move the signal source to the input of the preceding stage, and observe the signal. Continue moving the signal source to the inputs of successive stages.

When you inject the signal source to the input of the defective stage, there will be no output. Prevent stage overload by reducing the level of the injected signal as testing progresses through the circuit. Use suitable frequencies for each tested stage.

Make a rough check of stage gain by injecting a signal at the input and output of an amplifier stage. You can then compare how much louder the signal is when injected at the input. This test may mislead you if there is a radical difference in impedance from stage input to output. Understand the circuit operation before testing.

Mixer stages present a special problem because they have two inputs, rather than one. A lack of output signal from a mixer can be caused by either a faulty mixer or a faulty local oscillator (LO). Check oscillator operation with an oscilloscope or by listening on another receiver. If none of these instruments are available, inject the frequency of the LO at the LO output. If a dead oscillator is the only problem, this should restore operation.

If the oscillator is operating, but off frequency, a multitude of spurious responses will appear. A simple signal injector that produces many frequencies simultaneously is not suitable for this test. Use a well-shielded signal generator set to an appropriate level at the LO frequency.

Divide and Conquer

If the equipment has a single primary signal path, the block-by-block search may be sped up considerably by testing between successively smaller groups of circuit blocks. Each test thus exercises some fraction of the remaining circuit.

This "divide and conquer" tactic cannot be used in equipment that splits the signal path between the input and the output. Test readings taken inside feedback loops are misleading unless you understand the circuit and the waveform to be expected at each point in the test circuit. It is best to consider all stages within a feedback loop as a single block during the block search.

Divide-and-conquer is a good tactic for those inclined to take the instinctive approach to troubleshooting. As you gain more experience, you'll find yourself able to quickly isolate problems this way. You can then test each block in more detail.

26.4.5 Microprocessor-Controlled Equipment

The majority of today's amateur equipment and accessories have at least one microprocessor and sometimes several. While reliability of this equipment is greatly improved over the older analog designs, troubleshooting microprocessor-based circuitry takes a different approach. While a tutorial on microprocessor troubleshooting is well outside the scope of this *Handbook*, the following basic guidelines will help determine whether the problem is inside the microprocessor (or its firmware) or in the supporting circuitry. In addition, the **Digital Basics** chapter contains lots of information about the operation of digital circuits.

1) Start by obtaining the microprocessor datasheet and identifying all of the power and control pins if they are not identified on the equipment schematic. Determine which state the control pins should be in for the device to run.

2) Test all power and control pins for the proper state (voltage). Verify that the microprocessor clock signal is active. If not, determine the reason and repair before proceeding.

3) If there is an address and data bus for external memory and input-output (I/O) devices (less common in newer equipment), use a logic probe or scope to verify that they are all active (changing state). If not, there is a program or logic fault.

4) Determine which pins are digital inputs or outputs of the microprocessor and verify that a valid digital logic level exists at the pin. If not, check the external circuit to which the pin is attached.

5) Determine which pins are analog inputs or outputs of the microprocessor. Analyze the external circuit to determine what constitutes a proper voltage into or out of the processor. If the voltage is not valid, check the external circuit to which the pin is attached. If an external voltage reference is used, verify that it is working.

6) External circuits can often be checked by disconnecting them from the microprocessor and either driving them with a temporary voltage source or measuring the signal they are attempting to send to the microprocessor.

7) If all control and power signals and the external circuitry checks out OK, it is likely that a microprocessor or firmware fault has occurred.

If you determine that the microprocessor is faulty, you will have to contact the manufacturer in most cases, since firmware is most often contained within the processor which must be programmed before it is installed. Older equipment in which the program and data memory are external to the microprocessor can be very difficult to repair due to obsolescence of the parts themselves and the requirement to program EPROM or PROM devices.

26.5 Testing at the Circuit Level

Once you have followed all of the troubleshooting procedures and have isolated your problem to a single defective stage or circuit, a few simple measurements and tests will usually pinpoint one or more specific components that need adjustment or replacement.

First, check the parts in the circuit against the schematic diagram to be sure that they are reasonably close to the design values, especially in a newly built circuit. Even in a commercial piece of equipment, someone may have incorrectly changed them during attempted repairs. A wrong-value part is quite likely in new construction, such as a homebrew or kit project.

26.5.1 Voltage Levels

Check the circuit voltages. If the voltage levels are printed on the schematic, this is easy. If not, analyze the circuit and make some calculations to see what the circuit voltages should be. Remember, however, that the printed or calculated voltages are nominal; measured voltages may vary from the calculations.

When making measurements, remember the following points:

- Make measurements at device leads, not at circuit-board traces or socket lugs.
- Use small test probes to prevent accidental shorts.
- Never connect or disconnect power to solid-state circuits with the switch on.
- Remember that voltmeters, particularly older analog meters may load down a high-impedance circuit and change the voltage, as will ×1 and low-impedance scope probes.

Voltages may give you a clue to what is wrong with the circuit. If not, check the active device. If you can check the active device in the circuit, do so. If not, remove it and test it, or substitute a known good device. After connections, most circuit failures are caused directly or indirectly by a bad active device. The experienced troubleshooter usually tests or substitutes these first. Analyze the other components and determine the best way to test each as described earlier.

There are two voltage levels in most analog circuits (V+ and ground, for example). Most component failures (opens and shorts) will shift dc voltages near one of these levels. Typical failures that show up as incorrect dc voltages include: open coupling transformers; shorted capacitors; open, shorted or overheated resistors and open or shorted semiconductors.

Digital logic circuits require that signals be within specific voltage ranges to be treated as a valid logic-low or logic-high value.

26.5.2 Noise

A slight hiss is normal in all electronic circuits. This noise is produced whenever current flows through a conductor that is warmer than absolute zero. Noise is compounded and amplified by succeeding stages. Repair is necessary only when noise threatens to obscure normally clear signals.

Semiconductors can produce hiss in two ways. The first is normal — an even white noise that is much quieter than the desired signal. Faulty devices frequently produce excessive noise. The noise from a faulty device is often erratic, with pops and crashes that are sometimes louder than the desired signal. In an analog circuit, the end result of noise is usually sound. In a control or digital circuit, noise causes erratic operation: unexpected switching and so on.

Noise problems usually increase with temperature, so localized heat may help you find the source. Noise from any component may be sensitive to mechanical vibration. Tapping various components with an insulated screwdriver may quickly isolate a bad part. Noise can also be traced with an oscilloscope or signal tracer.

Nearly any component or connection can be a source of noise. Defective components are the most common cause of crackling noises. Defective connections are a common cause of loud, popping noises.

Check connections at cables, sockets and switches. Look for dirty variable capacitor wipers and potentiometers. An arcing mica trimmer capacitor can create static crashes in received or transmitted audio. Test them by installing a series 0.01 µF capacitor. If the noise disappears, replace the trimmer.

Potentiometers are particularly prone to noise problems when used in dc circuits. Clean them with a spray contact cleaner and rotate the shaft several times.

Rotary switches may be tested by jumpering the contacts with a clip lead. Loose contacts may sometimes be repaired, either by cleaning, carefully rebending the switch contacts or gluing loose switch parts to the switch deck. Operate variable components through their range while observing the noise level at the circuit output.

26.5.3 Oscillations

Oscillations occur whenever there is sufficient positive feedback in a circuit that has gain. (This can even include digital devices.) Oscillation may occur at any frequency from a low-frequency "putt-putt" (often called *motorboating*) well up into the RF region.

Unwanted oscillations are usually the result of changes in the active device (increased junction or interelectrode capacitance), failure of an oscillation suppressing component (open decoupling or bypass capacitors or neutralizing components) or new feedback paths (improper lead dress or dirt on the chassis or components). It can also be caused by improper design, especially in home-brew circuits. A shift in bias or drive levels may aggravate oscillation problems.

Oscillations that occur in audio stages do not change as the radio is tuned because the operating frequency — and therefore the component impedances — do not change. RF and IF oscillations, however, usually vary in amplitude as operating frequency is changed.

Oscillation stops when the positive feedback is removed. Locating and replacing a defective (or missing) bypass capacitor may effect an improvement. The defective oscillating stage can be found most reliably with an oscilloscope.

26.5.4 Amplitude Distortion

Amplitude distortion is the product of nonlinear operation. The resultant waveform contains not only the input signal, but new signals at other frequencies as well. All of the frequencies combine to produce the distorted waveform. Distortion in a transmitter gives rise to splatter, harmonics and interference.

Fig 26.15 shows some typical cases of distortion. Clipping (also called flat-topping) is the consequence of excessive drive, a change in bias, or insufficient supply voltage to the circuit. The corners on the waveform show that harmonics are present. (A square wave contains the fundamental and all odd harmonics.) If this was a transmitter circuit, these odd harmonics would be heard well away from the operating frequency, possibly outside of amateur bands.

Harmonic distortion produces radiation at frequencies far removed from the fundamental; it is a major cause of electromagnetic interference (EMI). Harmonics are generated

Controlling Key Clicks

Key clicks are a special type of amplitude distortion caused by fast rising and falling edges of the output waveform or from abrupt disturbances in an otherwise smooth waveform. See the **Transmitters and Transceivers** chapter for more information about controlling key clicks. Most modern radios offer user configuration options to adjust keying rise and fall times. Older radios may require modification of a timing circuit that controls rise and fall time. Be a good neighbor to other operators and eliminate key clicks on your signal!

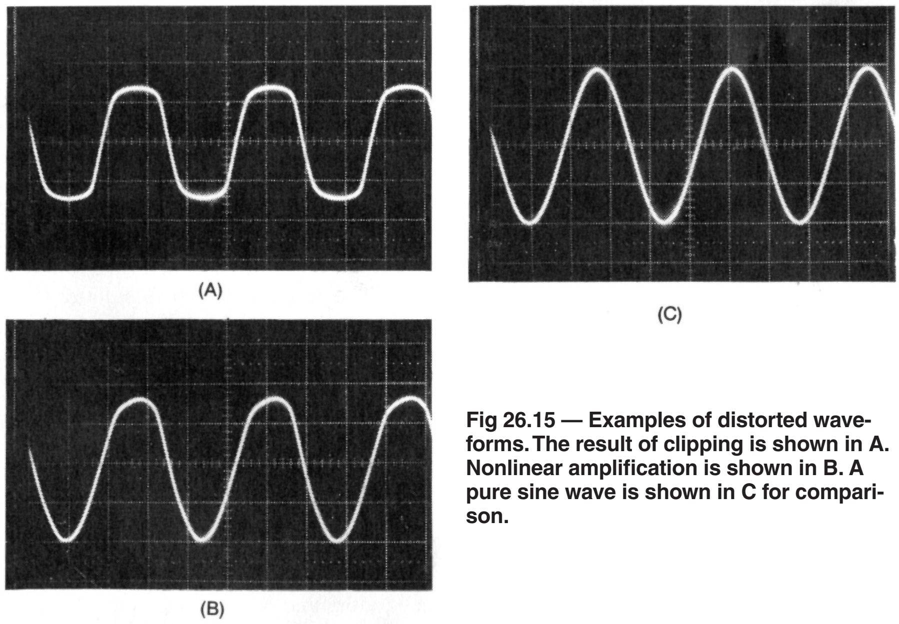

Fig 26.15 — Examples of distorted waveforms. The result of clipping is shown in A. Nonlinear amplification is shown in B. A pure sine wave is shown in C for comparison.

in nearly every amplifier. When they occur in a transmitter, they are usually caused by insufficient transmitter filtering (either by design, or because of filter component failure).

Anything that changes the proper bias of an amplifier can cause distortion. This includes failures in the bias components, leaky transistors or vacuum tubes with interelectrode shorts. In a receiver, these conditions may mimic AGC trouble. Improper bias of an analog circuit often results from a resistor that changed value or a leaky or shorted capacitor. RF feedback can also produce distortion by disturbing bias levels. Distortion is also caused by circuit imbalance in Class AB or B amplifiers.

Oscillations in an IF amplifier may produce distortion. They cause constant, full AGC action, or generate spurious signals that mix with the desired signal. IF oscillations are usually evident on the S meter, which will show a strong signal even with the antenna disconnected.

26.5.5 Frequency Response

Every circuit, even a broadband circuit, has a desired frequency response. Audio amplifiers used in amateur SSB circuits, for example, typically are designed for signals between 300 and 3000 Hz, more or less. A tuned IF amplifier may have a bandwidth of 50 to 100 kHz around the stage's center frequency. Any change in the circuit's frequency response can alter its effect on the signals on which it operates.

Frequency response changes are almost always a consequence of a capacitor or inductor changing value. The easiest way to check frequency response is to either inject a signal into the circuit and measure the output at several frequencies or use a spectrum analyzer or a signal generator's sweep function. In LC networks, it is relatively simple to lift one lead of the component and use a component checker to determine the value.

26.5.6 Distortion Measurement

A distortion meter is used to measure distortion of AF signals. A spectrum analyzer is the best piece of test gear to measure distortion of RF signals. If a distortion meter is not available, an estimation of AF distortion can sometimes be made with a function generator and an oscilloscope. Inject a square wave signal into the circuit with a fundamental frequency roughly in the middle of the expected frequency response.

Compare the input square wave to the output signal with an oscilloscope. **Fig 26.16** shows several effects on the square wave that are related to frequency response. These provide clues to what components or devices may be causing the problem. Severe distortion indicates some other problem besides frequency response changes.

26.5.7 Alignment

Alignment — the tuning or calibration of frequency sensitive circuits — is rarely the cause of an electronics problem with receiving or transmitting equipment, particularly modern equipment. Alignment does not shift suddenly and should be a last resort for treating sensitivity or frequency response problems. Do not attempt to adjust alignment without the proper equipment and alignment procedures. The process often requires steps to be performed exactly and in a specific order. Equipment misaligned in this way usually must be professionally repaired as a consequence.

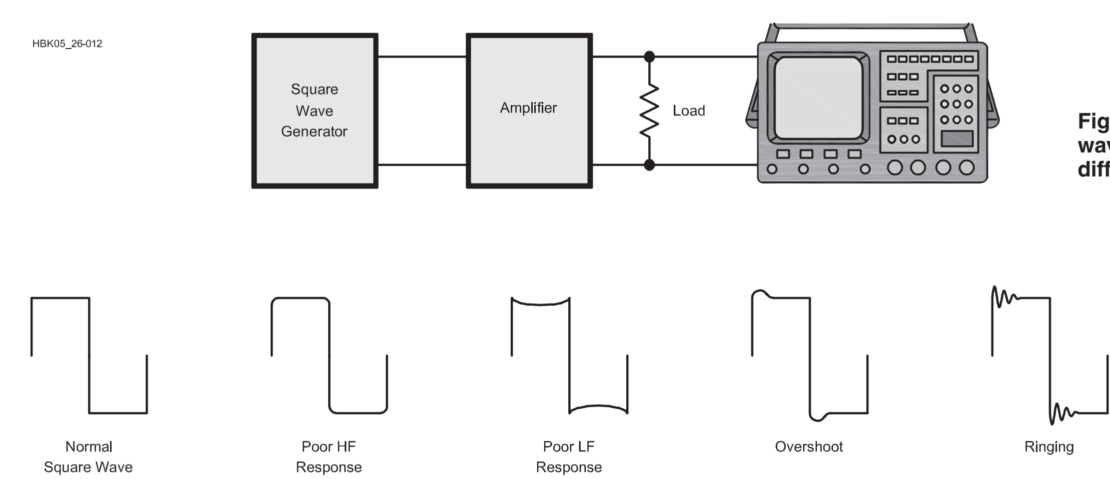

Fig 26.16 — Square-wave distortion from different causes.

26.5.8 Contamination

Contamination is another common service problem. Soda or coffee spilled into a piece of electronics is an extreme example (but one that does actually happen).

Conductive contaminants range from water to metal filings. Most can be removed by a thorough cleaning. Any of the residue-free cleaners can be used, but remember that the cleaner may also be conductive. Do not apply power to the circuit until the area is completely dry.

Keep cleaners away from variable-capacitor plates, transformers and parts that may be harmed by the chemical. The most common conductive contaminant is solder, either from a printed-circuit board solder bridge or a loose piece of solder deciding to surface at the most inconvenient time.

High-voltage circuits attract significant amounts of dust as described in the section on high-power amplifier maintenance later in this chapter. Cooling fans and ventilation holes also allow dust to accumulate, creating conductive paths between components. If not removed, the conductive paths gradually become lower in resistance until they begin to affect equipment performance. Vacuuming or blowing out the equipment is usually sufficient to clear away dust, although a carbon track may require a more thorough cleaning.

26.5.9 Solder Bridges

In a typical PC-board solder bridge, the solder that is used to solder one component has formed a short circuit to another PC-board trace or component. Unfortunately, they are common in both new construction and repair work. Look carefully for them after you have completed any soldering, especially on a PC-board. It is even possible that a solder bridge may exist in equipment you have owned for a long time, unnoticed until it suddenly decided to become a short circuit.

Related items are loose solder blobs, loose hardware or small pieces of component leads that can show up in the most awkward and troublesome places.

26.5.10 Arcing

Arcing is a serious sign of trouble. It may also be a real fire hazard. Arc sites are usually easy to find because an arc that generates visible light or noticeable sound also pits and discolors conductors.

Arcing is caused by component failure, dampness, dirt or lead dress. If the dampness is temporary, dry the area thoroughly and resume operation. Dirt may be cleaned from the chassis with a residue-free cleaner. Arrange leads so high-voltage conductors are isolated. Keep them away from sharp corners and screw points.

Arcing occurs in capacitors when the working voltage is exceeded. Air-dielectric variable capacitors can sustain occasional arcs without damage, but arcing indicates operation beyond circuit limits. Antenna tuners working beyond their ability may suffer from arcing. A failure or high SWR in an antenna circuit may also cause transmitter arcing. Prolonged, repeated, or high-power arcing can cause pits or deposits on capacitor plates that reduce capacitor voltage rating and lead to more arcing.

26.5.11 Digital Circuitry

Although every aspect of digital circuit operation may be resolved to a simple 1 or 0, or tristate (open circuit), the symptoms of their failure are far more complicated. The most common problems are false triggers or counts, digital inputs that do not respond to valid logic signals, and digital outputs stuck at ground or the supply voltage.

In most working digital circuitry the signals are constantly changing between low and high states, often at RF rates. Low-frequency or dc meters should not be used to check digital signal lines. A logic probe is often helpful in determining signal state and whether it is active or not. An oscilloscope or logic analyzer is usually needed to troubleshoot digital circuitry beyond simple go/no-go testing.

If you want to use an oscilloscope to give an accurate representation of digital signals, the scope bandwidth must be at least several times the highest clock frequency in the circuit in order to reproduce the fast rise and fall times of digital signals. Lower-bandwidth scopes can be useful in determining whether a signal is present or active but often miss short glitch signals (very fast transients) that are often associated with digital circuit malfunction.

LOGIC LEVELS

Begin by checking for the correct voltages at the pins of each IC. The correct logic voltages are specified in the device's datasheet, which will also identify the power pins (V_{cc} and ground). The voltages on the other pins should be a logic high, a logic low, or tristate (more on this later).

Most digital circuit failures are caused by a failed logic IC. IC failures are almost always catastrophic. It is unlikely that an AND gate will suddenly start functioning like an OR gate. It is more likely that the gate will have a signal at its input, and no signal at the output. In a failed device, the output pin will have a steady voltage. In some cases, the voltage is steady because one of the input signals is missing. Look carefully at what is going into a digital IC to determine what should be coming out. Manufacturers' datasheets describe the proper functioning of most digital devices.

TRISTATE DEVICES

Many digital devices are designed with a third logic state, commonly called tristate. In this state, the output of the device acts as an open circuit so that several device outputs can be connected to a common bus. The outputs that are active at any given time are selected by software or hardware control signals. A computer's data and address busses are good examples of this. If any device output connected to the bus fails by becoming locked or stuck in a 0 or 1 logic state, the entire bus becomes nonfunctional. Tristate devices can also be locked on by a failure of the signal that controls the tristate output status.

SIMPLE GATE TESTS

Most discrete logic ICs (collections of individual gates or other logic functions) are easily tested by in-circuit inspection of the input and output signals. The device's truth table or other behavior description specifies what the proper input and output signals should be. Testing of more complicated ICs requires the use of a logic analyzer, multitrace scope or a dedicated IC tester. If a simple logic IC is found to be questionable, it is usually easiest to simply substitute a new device for it.

CLOCK SIGNALS

In clocked circuits, check to see if the clock signal is active. If the signal is found at the clock chip, trace it to each of the other ICs to be sure that the clock system is intact. Clock frequencies are rarely wrong but clock signals derived from a master clock can be missing or erratic if the circuitry that creates them is defective.

RF INTERFERENCE

If digital circuitry interferes with other nearby equipment, it may be radiating spurious signals. These signals can interfere with your Amateur Radio operation or other services. Computer networking and microprocessor-controlled consumer equipment generate a significant amount of noise due to RF being radiated from cables and unshielded equipment.

Digital circuitry can also be subject to interference from strong RF fields. Erratic operation or a complete lock-up is often the result. Begin by removing the suspect equipment from RF fields. If the symptoms stop when there is no RF energy present, apply common-mode chokes as described in the **RF Interference** chapter..

The ARRL RFI Book has a chapter on computer and digital interference to and from digital devices and circuits. The subject is also covered in the **RF Interference** chapter of this book.

26.5.12 Replacing Parts

If you have located a defective component within a stage, you need to replace it. When replacing socket mounted components, be sure to align the replacement part correctly. Make sure that the pins of the device are properly inserted into the socket. See the **Construction Techniques** chapter for guidance on working with SMT components.

Some special tools can make it easier to remove soldered parts. A chisel-shaped soldering tip helps pry leads from printed-circuit boards or terminals. A desoldering iron or bulb forms a suction to remove excess solder, making it easier to remove the component. Spring-loaded desoldering pumps are more convenient than bulbs. Desoldering wick draws solder away from a joint when pressed against the joint with a hot soldering iron.

Removing soldered ICs is a lot simpler if you simply clip its leads next to the IC body using fine-point wire cutters, although it does destroy the IC. Then melt the solder and lift out the pin with tweezers or the wire cutter. Use the desoldering pumps or wick to remove the solder. This works well for both through-hole and SMT components.

26.6 After the Repairs

Once you have completed your troubleshooting and repairs, it is time to put the equipment back together. Take a little extra time to make sure you have done everything correctly.

26.6.1 All Units

Give the entire unit a complete visual inspection. Look for any loose ends left over from your troubleshooting procedures — you may have left a few components temporarily soldered in place, forgotten to reattach a wire or cable, or overlooked some other repair error. Look for cold solder joints and signs of damage incurred during the repair. Double-check the position, leads and polarity of components that were removed or replaced.

Make sure that all ICs and connectors are properly oriented and inserted in their sockets. Test fuse continuity with an ohmmeter and verify that the current rating matches the circuit specification.

Look at the position of all of the wires and components. Make sure that wires and cables will be clear of hot components, screw points and other sharp edges. Make certain that the wires and components will not be in the way and pinched or crimped when covers are installed and the unit is put back together.

Separate the leads that carry dc, RF, input and output as much as possible. Plug-in circuit boards should be firmly seated with screws tightened and lock washers installed if so specified. Shields and ground straps should be installed just as they were on the original.

26.6.2 Transmitter Checkout

Since the signal produced by an HF transmitter can be heard the world over, a thorough check is necessary after any service has been performed. Do not exceed the transmitter duty cycle while testing. Limit transmissions to 10 to 20 seconds unless otherwise specified by the owner's manual.

1. Set all controls as specified in the operation manual, or at midscale.

2. Connect a dummy load and a power meter to the transmitter output.

3. Set the drive or carrier control for low output.

4. Switch the power on.

5. Transmit and quickly set the final-amplifier bias to specifications if necessary

6. For vacuum tube final amplifiers, slowly tune the output network through resonance. The current dip should be smooth and repeatable. It should occur simultaneously with the maximum power output. Any sudden jumps or wiggles of the current meter indicate that the amplifier is unstable. Adjust the neutralization circuit (according to the manufacturer's instructions) if one is present or check for oscillation. An amplifier usually requires neutralization whenever active devices, components or lead dress (that affect the output/input capacitance) are changed.

7. Check to see that the output power is consistent with the amplifier class used in the PA (efficiency should be about 25% for Class A, 50 to 60% for Class AB or B, and 70 to 75% for Class C). Problems are indicated by the efficiency being significantly low.

8. Repeat steps 4 through 6 for each band of operation from lowest to highest frequency.

9. Check the carrier balance (in SSB transmitters only) and adjust for minimum power output with maximum RF drive and no microphone gain.

10. Adjust the VOX controls.

11. Measure the passband and distortion levels if equipment (wideband scope or spectrum analyzer) is available.

26.6.3 Other Repaired Circuits

After the preliminary checks, set the circuit controls per the manufacturer's specifications (or to midrange if specifications are not available) and switch the power on. Watch and smell for smoke, and listen for odd sounds such as arcing or hum. Operate the circuit for a few minutes, consistent with allowable duty cycle. Verify that all operating controls function properly.

Check for intermittent connections by subjecting the circuit to heat, cold and slight flexure. Also, tap or jiggle the chassis lightly with an alignment tool or other insulator.

If the equipment is meant for mobile or portable service, operate it through an appropriate temperature range. Many mobile radios do not work on cold mornings, or on hot afternoons, because a temperature-dependent intermittent was not found during repairs.

26.6.4 Button It Up

After you are convinced that you have repaired the circuit properly, put it all back together. If you followed the advice in this book, you have all the screws and assorted doodads in a secure container. Look at the notes you took while taking it apart; put it back together in the reverse order. Don't forget to reconnect all internal connections, such as ac power, speaker or antenna leads.

Once the case is closed, and all appears well, don't neglect the final, important step — make sure it still works. Many an experienced technician has forgotten this important step, only to discover that some minor error, such as a forgotten antenna cable, has left the equipment nonfunctional.

26.7 Professional Repairs

Repairs that deal with very complex and temperamental circuits, or that require sophisticated test equipment, should be passed on to a professional. Factory authorized service personnel have a lot of experience. What seems like a servicing nightmare to you is old hat to them. There is no one better qualified to service your equipment than the factory.

If the manufacturer is no longer in business, check with your local dealer or look through Amateur Radio magazines and websites. You can usually find one or more companies or repair services that handle all makes and models. Your local club or a user's group may also be able to make a recommendation.

If you are going to ship your equipment somewhere for repair, notify the repair center first. Get authorization for shipping and an identification name or number for the package.

26.7.1 Packing Equipment

You can always blame shipping damage on the shipper, but it is a lot easier for all concerned if you package your equipment properly for shipping in the first place.

- Take photos of the equipment before packing it to document its condition before shipping. Additional photos during the packing steps might also be useful to show that you took the proper care in packing the equipment.

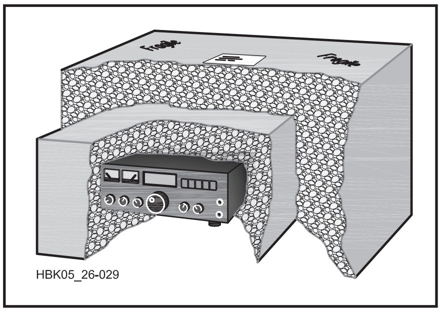

Fig 26.17 — Ship equipment packed securely in a box within a box.

- Firmly secure all heavy components, either by tying them down or blocking them off with shipping foam.
- Large transformers, such as for RF power amplifiers, should probably be removed and shipped separately.
- Large vacuum tubes should be wrapped in packing material or shipped separately.
- Make sure that all circuit boards and parts are firmly attached.

If you have the original shipping container, including all of the packing material, you should use that if the repair facility approves doing so. Otherwise use a box within a box for shipping. (See **Fig 26.17**). Place the equipment and some packing material inside a box and seal it with tape. Place that box inside another that is at least six inches larger in each dimension.

Don't forget to enclose a statement of the trouble, a short history of operation and any test results that may help the service technician. Include a good description of the things you have tried. Be honest! At current repair rates you want to tell the technician everything to help ensure an efficient repair. Place the necessary correspondence, statement of symptoms, and your contact information in a mailing envelope and place it just inside the top covers of the outer box or tape it to the top of the inner box.

Fill any remaining gaps with packing material, seal, address and mark the outer box. Choose a good freight carrier and insure the package. If available, get a tracking number for the package so you can tell when it was delivered.

Even if you tried to fix it yourself but ended up sending it back to the factory, you can feel good about your experience. You learned a lot by trying, and you have sent it back knowing that it really did require the services of a pro. Each time you troubleshoot and repair a piece of electronic circuitry, you learn something new. The down side is that you may develop a reputation as a real electronics whiz. You may find yourself spending a lot of time at club meetings offering advice, or getting invited over to a lot of shacks for a late-evening pizza snack. There are worse fates.

26.8 Typical Symptoms and Faults

26.8.1 Power Supplies

Many equipment failures are caused by power supply trouble. Fortunately, most power supply problems are easy to find and repair. This section focuses on the common linear power supply. Some notes are also made about switchmode supplies. Both types are discussed in detail in the **Power Sources** chapter, including projects with typical schematics.

LINEAR POWER SUPPLIES

The block diagram for a linear power supply is shown in **Fig 26.18.** First, use a voltmeter to measure output. Complete loss of output voltage is usually caused by an open circuit. (A short circuit draws excessive current that opens the fuse, thus becoming an open circuit.) If output voltage appears normal, apply a small load (1/10th supply capacity or smaller) and test output voltage again. If the small load causes voltage to drop, there is generally a problem in the regulator circuitry, often the pass transistors.

If the ac input circuit fuse is blown, that is usually caused by a shorted diode in the filter block, a failure of the output protection circuitry, or a short circuit in the device being powered by the supply. More rarely, one of the filter capacitors can short. If the fuse has opened, turn off the power, replace the fuse, and measure the load-circuit's dc resistance. The measured resistance should be consistent with the power-supply ratings. A short or open load circuit indicates a problem.

If the measured resistance is too low, troubleshoot the load circuit. (Nominal circuit resistances are included in some equipment manuals.) If the load circuit resistance is normal, suspect a defective regulator IC or problem in the rest of the unit.

IC regulators can oscillate, sometimes causing failure. The small-value capacitors on the input, output or adjustment pins of the regulator prevent oscillations. Check or replace these capacitors whenever a regulator has failed.

AC ripple (120 Hz buzz) is usually caused

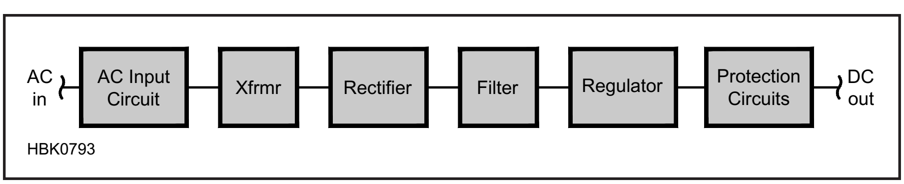

Fig 26.18 — Block diagram of a typical linear power supply.

by low-value filter capacitors in the power supply. Ripple can also become excessive due to overload or regulation problems. Look for a defective filter capacitor (usually open or low-value), defective regulator, or shorted filter choke if chokes are used (not common in modern equipment). In older equipment, the defective filter capacitor will often have visible leaking electrolyte: Look for corrosion residue at the capacitor leads. In new construction projects make sure RF energy is not getting into the power supply.

Here's an easy filter capacitor test: Temporarily connect a replacement capacitor (about the same value and working voltage) across the suspect capacitor. If the hum goes away, replace the bad component permanently.

Once the faulty component is found, inspect the surrounding circuit and consider what may have caused the problem. Sometimes one bad component can cause another to fail. For example, a shorted filter capacitor increases current flow and burns out a rectifier diode. While the defective diode is easy to find, the capacitor may show no visible damage.

If none of these initial checks find the problem, here are the usual systematic steps to locate the part of the supply with a problem:

- Check the input ac through switches and fuses to the transformer primary.
- Verify that the transformer secondary outputs ac of the right voltage. Disconnect the output leads, if necessary.
- Check the rectifiers for shorted diodes. Disconnect the rectifier output and test for output with a resistor load.
- Reconnect the filter and disconnect the regulator. Verify that the right dc voltage is present at the filter output.
- Reconnect the regulator and in the regulator IC or circuit, test every pin or signal, especially enable/disable/soft-start and the voltage reference.
- Disconnect any output protective circuitry and verify that the pass transistors are working with a resistor load.
- Reconnect and test the output protective circuitry.

SWITCHMODE POWER SUPPLIES

Switchmode or switching power supplies are quite different from conventional supplies. In a switcher, the regulator circuit is based on a switching transistor and energy storage inductor instead of a pass transistor to change power from one dc level to another that can be higher or lower than the input voltage. Switching frequencies range from 20-120 kHz for most supplies and up to the MHz range for miniature dc-dc converter modules.

Switchmode supplies operating from the ac line have similar input circuits to linear supplies. The transformer that supplies isolation is then located in the low-voltage, high frequency section.

Apply the same input and output block-level tests as for linear supplies. The regulator circuitry in a swichmode supply is more complex than for a linear supply, but it usually is implemented in a single regulator IC. Failure of the regulator IC, transistor switch, or feedback path usually results in a completely dead supply. While active device failure is still the number one suspect, it pays to carefully test all components in the regulator subsystem.

HIGH-VOLTAGE POWER SUPPLIES

Obviously, testing HV supplies requires extreme caution. See the safety discussion at the beginning of this chapter, the **Safety** chapter of this book, and the discussion of HV supplies in the **Power Sources** chapter. If you do not feel comfortable working on HV supplies, then don't. Ask for help or hire a professional repair service to do the job.

Most HV supplies used in amateur equipment are linear supplies with the same general structure as low voltage supplies. A typical supply is presented as a project in the **Power Sources** chapter and the same basic steps can be applied — just with a lot more caution.

Components in a string, such as rectifiers or filter capacitors, should all be tested if any are determined to have failed. This is particularly true for capacitors which can fail in sequence if one capacitor in the string shorts. Voltage equalizing resistors are not required for rectifier diodes available today such as the 1N5408. Consider replacing older rectifier strings with new rectifiers as a preventive maintenance step.

Interlocks rarely fail but verify that they are functioning properly before assuming they are in good working order.

26.8.2 Amplifier Circuits

Amplifiers are the most common circuits in electronics. The output of an ideal amplifier would match the input signal in every respect except magnitude: No distortion or noise would be added. Real amplifiers always add noise and distortion. Typical discrete and op-amp amplifier circuits are described in the **Analog Basics** chapter.

AMPLIFIER GAIN

Amplifier failure usually results in a loss of gain or excessive distortion at the amplifier output. In either case, check external connections first. Is there power to the stage? Has the fuse opened? Check the speaker and leads in audio output stages, the microphone and push-to-talk (PTT) line in transmitter audio sections. Excess voltage, excess current or thermal runaway can cause sudden failure of semiconductors. The failure may appear as either a short circuit or open circuit of one or more PN junctions.

Thermal runaway occurs most often in bipolar transistor circuits. If degenerative feedback (the emitter resistor reduces base-emitter voltage as conduction increases) is insufficient, thermal runaway will allow excessive current flow and device failure. Check transistors by substitution, if possible. If not, voltage checks as described below usually turn up the problem.

Faulty coupling components can reduce amplifier output. Look for component failures that would increase series impedance, or decrease shunt impedance, in the coupling network. Coupling faults can be located by signal tracing or parts substitution. Other passive component defects reduce amplifier output by shifting bias or causing active-device failure. These failures are evident when the dc operating voltages are measured.

If an amplifier is used inside a feedback loop, faults in the feedback loop can force a transistor into cutoff or saturation or force an op amp's output to either power supply rail. In a receiver, the AGC subsystem is such a feedback loop. Open the AGC line to the device and substitute a variable voltage for the AGC signal. If amplifier action varies with voltage, suspect the AGC-circuit components; otherwise, suspect the amplifier.

In an operating amplifier, check carefully for oscillations or noise. Oscillations are most likely to start with maximum gain and the amplifier input shorted. Any noise that is due to 60 Hz sources can be heard, or seen with an oscilloscope triggered by the ac line.

Unwanted amplifier RF oscillations should be cured with changes of lead dress or circuit components. Separate input leads from

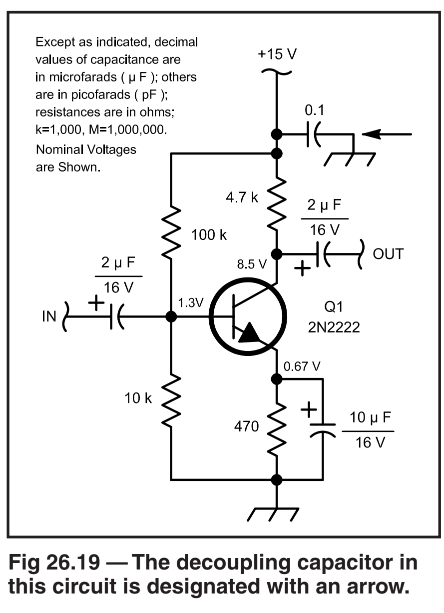

Fig 26.19 — The decoupling capacitor in this circuit is designated with an arrow.

output leads; use coaxial cable to carry RF between stages; neutralize inter-element or junction capacitance. Ferrite beads on the control element of the active device often stop unwanted oscillations.

Low-frequency oscillations (motorboating) indicate poor stage isolation or inadequate power supply filtering. Try a better lead-dress arrangement and/or check the capacitance of the decoupling network (see **Fig 26.19**). Use larger capacitors at the power supply leads; increase the number of capacitors or use separate decoupling capacitors at each stage. Coupling capacitors that are too low in value can also cause poor low-frequency response. Poor response to high frequencies is usually caused by circuit design.

COMMON-EMITTER AMPLIFIER

The common-emitter circuit (or common-source using an FET) is the most widely used configuration. It can be used as an amplifier or as a switch. Both are analyzed here as an example of how to troubleshoot transistor amplifier circuits. Other types of circuit can be analyzed similarly

Fig 26.20 is a schematic of a common-emitter transistor amplifier. The emitter, base and collector leads are labeled e, b and c, respectively. Important dc voltages are measured at the emitter (V_e), base (V_b) and collector (V_c) leads. V+ is the supply voltage.

First, analyze the voltages and signal levels in this circuit. The junction drop is the potential measured across a semiconductor junction that is conducting. It is typically 0.6 V for silicon and 0.2 V for germanium transistors.

This is a Class-A linear circuit. In Class-A circuits, the transistor is always conducting some current. R1 and R2 form a voltage divider that supplies dc bias (V_b) for the transistor. Normally, V_e is equal to V_b less the emitter-base junction drop. R4 provides degenerative dc bias, while C3 provides a low-impedance path for the signal. From this information, normal operating voltages can be estimated.

The bias and voltages will be set up so that the transistor collector voltage, V_c, is somewhere between V+ and ground potential. A good rule of thumb is that V_c should be about one-half of V+, although this can vary quite a bit, depending on component tolerances. The emitter voltage is usually a small percentage of V_c, say about 10%.

Any circuit failure that changes collector current, I_c, (ranging from a shorted transistor or a failure in the bias circuit) changes V_c and V_e as well. An increase of I_c lowers V_c and raises V_e. If the transistor shorts from collector to emitter, V_c drops to about 1.2 V, as determined by the voltage divider formed by R3 and R4.

You would see nearly the same effect if

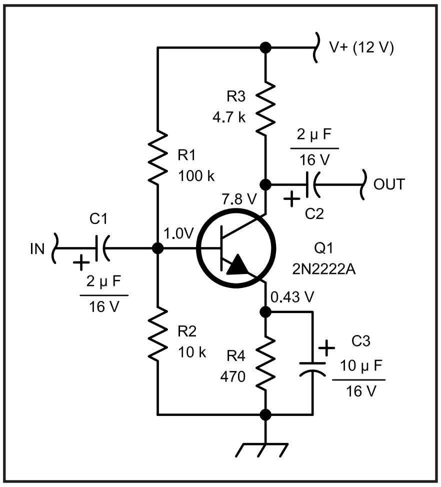

Fig 26.20 — A typical common-emitter audio amplifier.

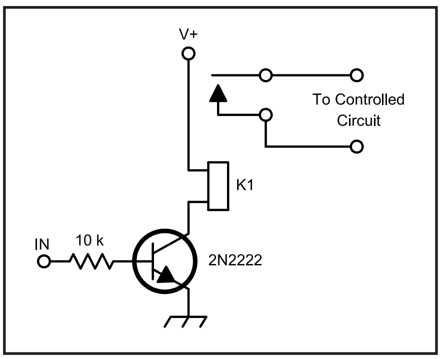

Fig 26.21 — A typical common-emitter switch or driver.

the transistor were biased into saturation by collector-to-base leakage, a reduction in R1's value or an increase in R2's value. All of these circuit failures have the same effect. In some cases, a short in C1 or C2 could cause the same symptoms.

To properly diagnose the specific cause of low V_c, consider and test all of these parts. It is even more complex; an increase in R3's value would also decrease V_c. There would be one valuable clue, however: if R3 increased in value, I_c would not increase; V_e would also be low.

Anything that decreases I_c increases V_c. If the transistor failed open, R1 increased in value, R2 were shorted to ground or R4 opened, then V_c would be high.

COMMON-EMITTER SWITCH

A common-emitter transistor switching circuit is shown in **Fig 26.21**. This circuit functions differently from the circuit shown in Fig 26.20. A linear amplifier is designed so that the output signal is a faithful reproduction of the input signal. Its input and output may have any value from V+ to ground.

The switching circuit of Fig 26.21, however, is similar to a digital circuit. The active device is either on or off, 1 or 0, just like digital logic. Its input signal level should either be 0 V or positive enough to switch the transistor on fully (saturate). Its output state should be either full off (with no current flowing through the relay), or full on (with the relay energized). A voltmeter placed on the collector will show either approximately +12 V or 0 V, depending on the input.

Understanding this difference in operation is crucial to troubleshooting the two circuits. If V_c were +12 V in the circuit in Fig 26.20, it would indicate a circuit failure. A V_c of +12 V in the switching circuit is normal when V_b is 0 V. (If V_b measured 0.8 V or higher, V_c should be low and the relay energized.)

DC-COUPLED AMPLIFIERS

In dc-coupled amplifiers, the transistors are directly connected together without coupling capacitors. They comprise a unique troubleshooting case. Most often, when one device fails, it destroys one or more other semiconductors in the circuit. If you don't find all of the bad parts, the remaining defective parts can cause the installed replacements to fail immediately. To reliably troubleshoot a dc coupled circuit, you must test every semiconductor in the circuit and replace them all at once.

26.8.3 Oscillators

In many circuits, a failure of the oscillator will result in complete circuit failure. A transmitter will not transmit, and a superheterodyne receiver will not receive if you have an internal oscillator failure. (These symptoms do not always mean oscillator failure, however.)

Whenever there is weakening or complete loss of signal from a radio, check oscillator operation and frequency. There are several methods:

- Use a receiver with a coaxial probe to listen for the oscillator signal.
- A dip meter can be used to check oscillators by tuning to within ±15 kHz of the oscillator, couple it to the circuit, and listen for a beat note in the dip-meter headphones.
- Look at the oscillator waveform on a scope. The operating frequency can't be determined with great accuracy, but you can see if the oscillator is working at all. Use a low capacitance (10×) probe for oscillator observations.

Many modern oscillators are phase-locked loops (PLLs). Read the **Oscillators and Synthesizers** chapter of this book in order to learn how PLLs operate.

To test for a failed LC oscillator, use a dip meter in the active mode. Set the dip meter to the oscillator frequency and couple it to the

oscillator output circuit. If the oscillator is dead, the dip-meter signal will take its place and temporarily restore some semblance of normal operation.

STABILITY

Drift is caused by variations in the oscillator. Poor voltage regulation and heat are the most common culprits. Check regulation with a voltmeter (use one that is not affected by RF). Voltage regulators are usually part of the oscillator circuit. Check them by substitution.

Chirp is a form of rapid drift that is usually caused by excessive oscillator loading or poor power-supply regulation. The most common cause of chirp is poor design. If chirp appears suddenly in a working circuit, look for component or design defects in the oscillator or its buffer amplifiers. (For example, a shorted coupling capacitor increases loading drastically.) Also check for new feedback paths from changes in wiring or component placement (feedback defeats buffer action).

Frequency instability may also result from defects in feedback components. Too much feedback may produce spurious signals, while too little makes oscillator start-up unreliable.

Sudden frequency changes are frequently the result of physical variations. Loose components or connections are probable causes. Check for arcing or dirt on printed-circuit boards, trimmers and variable capacitors, loose switch contacts, bad solder joints or loose connectors.

FREQUENCY ACCURACY

In manually tuned LC oscillators, tracking at the high-frequency end of the range is controlled by trimmer capacitors. A trimmer is a variable capacitor connected in parallel with the main tuning capacitor (see **Fig 26.22**). The trimmer represents a higher percentage of the total capacitance at the high end of the tuning range. It has relatively little effect on tuning characteristics at the low-frequency end of the range.

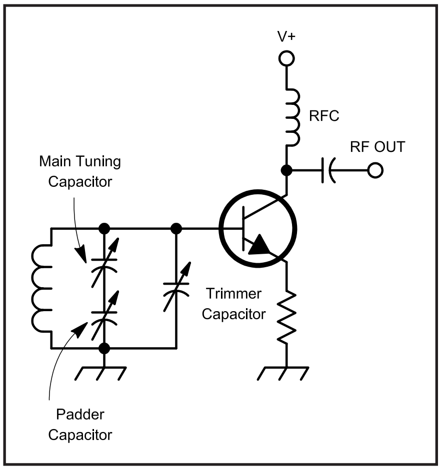

Fig 26.22 — A partial schematic of a simple oscillator showing the locations of the trimmer and padder capacitors.

Low-end range is adjusted by a series trimmer capacitor called a *padder*. A padder is a variable capacitor that is connected in series with the main tuning capacitor. Padder capacitance has a greater effect at the low-frequency end of the range. The padder capacitor is often eliminated to save money. In that case, the low-frequency range is set by adjusting the main tuning coil.

26.8.4 Transmit Amplifier Modules

Most VHF/UHF mobile radios and many small HF radios use commercial amplifier modules as the final amplifier instead of discrete transistors. These modules are quite reliable and can withstand various stresses such as disconnected antennas. However, replacement units are rarely available more than a few years after a particular radio model goes out of production. You may be able to find a damaged radio of the same model to scavenge for parts, but once the modules fail, you are usually out of luck. User's groups are often good sources of information about common failure modes of certain radios and possibly even sources of replacement parts.

The usual failure mode of an amplifier module is caused by thermal cycling that eventually leads to an internal connection developing a crack. The module becomes intermittent and then eventually fails completely. If you can open the module, you can sometimes identify and repair such a problem by soldering over the crack.

When reinstalling or replacing an amplifier module, be very careful to attach it to the heat sink as it was at the factory. Do not use excessive amounts of thermal compound or grease and make sure the mounting screws are secure. If you can find a datasheet for the module, check to see if there are recommendations for mounting screw torque and any other installation procedures. (See the **RF Power Amplifiers** chapter for guidelines on mounting power transistors.)

26.9 Radio Troubleshooting Hints

Tables 26.2, **26.3**, **26.4** and **26.5** list some common problems and possible cures for older radios that are likely to have developed problems with some later-model equivalents. These tables are not all-inclusive. They are a collection of hints and shortcuts that may save you some troubleshooting time. If you don't find your problem listed, continue with systematic troubleshooting.

Remember that many problems are caused by improper setting of a switch, a control, or a configuration menu item. Before beginning a troubleshooting session, be sure you've checked the operating manual for proper control settings and checked through the manual's troubleshooting guide. If possible, obtain a service manual with its detailed procedures, measurements, and schematics.

26.9.1 Receivers

A receiver can be diagnosed using any of the methods described earlier, but if there is not even a faint sound from the speaker, signal injection is not a good technique. If you lack troubleshooting experience, avoid following instinctive hunches. Begin with power supply tests and proceed to signal tracing.

SELECTIVITY

Failure of control or switching circuits that determine the signal path and filters can cause selectivity problems. In older equipment, tuned transformers or the components used in filter circuits may develop a shorted turn, capacitors can fail and alignment is required occasionally. Such defects are accompanied by a loss of sensitivity. Except in cases of catastrophic failure (where either the filter passes all signals, or none), it is difficult to spot a loss of selectivity. Bandwidth and insertion-loss measurements are necessary to judge filter performance.

SENSITIVITY

A gradual loss of sensitivity results from gradual degradation of an active device or long-term changes in component values. Sudden partial sensitivity changes are usually the result of a component failure, usually in the RF or IF stages. Excessive signal levels

Table 26.2
Symptoms and Their Causes for All Electronic Equipment

Symptom	*Cause*
Power Supplies	
No output voltage	Open circuit (usually a fuse, pass transistor, or transformer winding)
Hum or ripple	Faulty regulator, capacitor or rectifier, low-frequency oscillation
Amplifiers	
Low gain	Transistor, coupling capacitors, emitter-bypass capacitorAGC component
Noise	Transistors, coupling capacitors, resistors
Oscillations	Dirt on variable capacitor or chassis, shorted op-amp input
Oscillations, untuned (oscillations do not change with frequency)	Audio stages
Oscillations, tuned	RF, IF and mixer stages
Static-like crashes	Arcing trimmer capacitors, poor connections
Static in FM receiver	Faulty limiter stage, open capacitor in ratio detector, weak RF stage, weak incoming signal
Intermittent noise	All components and connections, band-switch contacts, potentiometers (especially in dc circuits), trimmer capacitors, poor antenna connections
Distortion (constant)	Oscillation, overload, faulty AGC, leaky transistor, open lead in tab-mount transistor, dirty potentiometer, leaky coupling capacitor, open bypass capacitors, imbalance in tuned FM detector, IF oscillations, RF feedback (cables)
Distortion (strong signals only)	Open AGC loop
Frequency change	Physical or electrical variations, dirty or faulty variable capacitor, broken switch, loose compartment parts, poor voltage regulation, oscillator tuning (trouble when switching bands)
No Signals	
All bands	Dead VFO or LO, PLL won't lock
One band only	Defective crystal, oscillator out of tune, band switch
No function control	Faulty switch or control, poor connection to front panel subassembly

Table 26.3
Receiver Problems

Symptom	*Cause*
Low sensitivity	Semiconductor degradation, circuit contamination, poor antenna connection
Signals and calibrator heard weakly	
(low S-meter readings)	RF chain
(strong S-meter readings)	AF chain, detector
No signals or calibrator heard, only hissing	RF oscillators
Distortion	
On strong signals only	AGC fault
AGC fault	Active device cut off or saturated
Difficult tuning	AGC fault
Inability to receive	Detector fault
AM weak and distorted	Poor detector, power or ground connection
CW/SSB unintelligible	BFO off frequency or dead
FM distorted	Open detector diode

or transients can damage input RF switching, amplifier, or mixing circuits. Complete and sudden loss of sensitivity is caused by an open circuit anywhere in the signal path or by a dead oscillator.

AGC

AGC failure usually causes distortion that affects only strong signals. All stages operate at maximum gain when the AGC influence is removed. An S meter can help diagnose AGC failure because it is operated by the AGC loop. If the S meter does not move at all or remains at full scale, the AGC system has a problem.

In DSP radios, the AGC function is often controlled by software which you cannot troubleshoot but inputs to the software such as signal level detectors may be causing a problem instead.

In analog receivers, an open bypass capacitor in the AGC amplifier causes feedback through the loop. This often results in a receiver squeal (oscillation). Changes in the loop time constant affect tuning. If stations consistently blast, or are too weak for a brief time when first tuned in, the time constant is too fast. An excessively slow time constant makes tuning difficult, and stations fade after tuning. If the AGC is functioning, but the timing seems wrong, check the large-value capacitors found in the AGC circuit — they usually set the AGC time constants. If the AGC is not functioning, check the AGC-detector circuit. There is often an AGC voltage that is used to control several stages. A failure in any one stage could affect the entire loop.

DETECTOR PROBLEMS

Detector trouble usually appears as complete loss or distortion of the received signal. AM, SSB and CW signals may be weak and unintelligible. FM signals will sound distorted. Look for an open circuit in the detector circuit. If tests of the detector parts indicate no trouble, look for a poor connection in the detector's power supply or ground connections. A BFO that is dead or off frequency prevents SSB and CW reception. In modern rigs, the BFO frequency is usually derived from the main VFO system.

26.9.2 Transmitters

Many potential transmitter faults are discussed in several different places in this chapter. There are, however, a few techniques used to ensure stable operation of RF amplifiers in transmitters that are not covered elsewhere.

RF final amplifiers often use parasitic chokes to prevent instability. Older parasitic chokes usually consist of a 51- to 100-Ω non-inductive resistor with a coil wound around the body and connected to the leads. It is

Table 26.4
Transmitter Problems

Symptom	*Cause*
Key clicks	Keying filter, distortion in stages after keying, ALC overshoot or instability
Modulation Problems	
Loss of modulation	Broken cable (microphone, PTT, power), open circuit in audio chain, defective modulator
Distortion on transmit	Defective microphone, RF feedback, modulator imbalance, bypass capacitor, improper bias, excessive drive
Arcing	Dampness, dirt, improper lead dress
Low output	Incorrect control settings, improper carrier shift (CW signal outside of passband) audio oscillator failure, transistor or tube failure, SWR protection circuit
Antenna Problems	
Poor SWR	Damaged antenna element, matching network, feed line, balun failure (see below), resonant conductor near antenna, poor connection at antenna
Balun failure	Excessive SWR, weather or cold-flow damage in coil choke, broken wire or connection
RFI	Arcing or poor connections anywhere in antenna system or nearby conductors

Table 26.5
Transceiver Problems

Symptom	*Cause*
Inoperative S meter	Faulty TR switching or relay
PA noise in receiver	Faulty TR switching or relay
Excessive current on receive	Faulty TR switching or relay
Arcing in PA	Faulty TR switching or relay
Reduced signal strength on transmit and receive	IF failure
Poor VOX operation	VOX amplifiers
Poor VOX timing	Adjustment, component failure in VOX timing circuits or amplifiers
VOX consistently tripped by receiver audio	AntiVOX circuits or adjustment

used to prevent VHF and UHF oscillations in a vacuum-tube amplifier. The suppressor is placed in the plate lead, close to the plate connection.

In recent years, problems with this style of suppressor have been discovered. See the **RF Power Amplifiers** chapter for information about suppressing parasitics. If parasitic suppressors are present in your transmitter, continue to use them as the exact layout and lead dress of the RF amplifier circuitry may require them to avoid oscillation. If they are not present, do not add them. When working on RF power amplifiers, take care to keep leads and components arranged just as they were when they left the factory.

Parasitic chokes often fail from excessive current flow. In these cases, the resistor is charred. Occasionally, physical shock or corrosion produces an open circuit in the coil. Test for continuity with an ohmmeter.

Transistor amplifiers are protected against parasitic oscillations by low-value resistors or ferrite beads in the base or collector leads. Resistors are used only at low power levels (about 0.5 W), and both methods work best when applied to the base lead. Negative feedback is used to prevent oscillations at lower frequencies. An open component in the feedback loop may cause low-frequency oscillation, especially in broadband amplifiers.

KEYING

The simplest form of modulation is on/off keying. Although it may seem that there cannot be much trouble with such an elementary form of modulation, two very important transmitter faults are the result of keying problems.

Key clicks are produced by fast rise and times of the keying waveform (see the previous sidebar, "Controlling Key Clicks"). Most transmitters include components in the keying circuitry to prevent clicks. When clicks are experienced, check the keying filter components first, then the succeeding stages. An improperly biased power amplifier, or a Class C amplifier that is not keyed, may produce key clicks even though the keying waveform earlier in the circuit is correct. Clicks caused by a linear amplifier may be a sign of low-frequency parasitic oscillations. If they occur in an amplifier, suspect insufficient power-supply decoupling. Check the power-supply filter capacitors and all bypass capacitors.

The other modulation problem associated with on/off keying is called backwave. Backwave is a condition in which the signal is heard, at a reduced level, even when the key is up. This occurs when the oscillator signal feeds through a keyed amplifier. This usually indicates a design flaw, although in some cases a component failure or improper keyed-stage neutralization may be to blame.

LOW OUTPUT POWER

Check the owner's manual to see if the condition is normal for some modes or bands, or if there is a menu item to set RF output power. Check the control settings. Solid-state transmitters require so little effort from the operator that control settings are seldom noticed. The CARRIER (or DRIVE) control may have been bumped. Remember to adjust tuned vacuum tube amplifiers after a significant change in operating frequency (usually 50 to 100 kHz). Most modern transmitters are also designed to reduce power if there is high (say 2:1) SWR. Check these obvious external problems before you tear apart your rig.

Power transistors may fail if the SWR protection circuit malfunctions. Such failures occur at the weak link in the amplifier chain: It is possible for the drivers to fail without damaging the finals. An open circuit in the reflected side of the sensing circuit leaves the transistors unprotected; a short shuts them down.

Low power output in a transmitter may also spring from a misadjusted carrier oscillator or a defective SWR protection circuit. If the carrier oscillator is set to a frequency well outside the transmitter passband, there may be no measurable output. Output power will increase steadily as the frequency is moved into the passband.

26.9.3 Transceivers

SWITCHING

Elaborate switching schemes are used in transceivers for signal control. Many transceiver malfunctions can be attributed to relay or switching problems. Suspect the switching controls when:

- The S meter is inoperative, but the unit otherwise functions. (This could also be a bad S meter or a consequence of a configuration menu item.)
- There is arcing in the tank circuit. (This could also be caused by a fault in the antenna system.)
- There is excessive broadband PA noise in the receiver.

Since transceiver circuits are shared, stage defects frequently affect both the transmit and receive modes, although the symptoms may change with mode. Oscillator problems usually affect both transmit and receive modes, but different oscillators, or frequencies, may be used for different emissions. Check the block diagram.

VOX

Voice operated transmit (VOX) controls are another potential trouble area. If there is difficulty in switching to transmit in the VOX mode, check the VOX-SENSITIVITY and ANTI-VOX control settings. Next, see if the PTT and manual (MOX) transmitter controls work. If the PTT and MOX controls function, examine the VOX control circuits. Test the switches, control lines and control voltage if the transmitter does not respond to other TR controls.

VOX SENSITIVITY and ANTI-VOX settings should also be checked if the transmitter switches on in response to received audio. Suspect the ANTI-VOX circuitry next. Unacceptable VOX timing results from a poor VOX-delay adjustment, or a bad resistor or capacitor in the timing circuit or VOX amplifiers.

26.9.4 Amplifiers

While this section focuses on vacuum-tube amplifiers using high-voltage (HV) supplies, it also applies to solid-state amplifiers that operate at lower voltages and generally have fewer points of failure. Amplifiers are simple, reliable pieces of equipment that respond well to basic care, regular maintenance and common sense. A well-maintained amplifier will provide reliable service and maximum tube lifetime. (The complete version of the original article is included on this book's CD-ROM.)

SAFETY FIRST

It is important to review good safety practices. (See the **Safety** and **Power Sources** chapters for additional safety information.) Tube amplifiers use power supply voltages well in excess of 1 kV and the RF output can be hundreds of volts, as well. Almost every voltage in an amplifier can be lethal! Take care of yourself and use caution!

Power Control — Know and control the state of both ac line voltage and dc power supplies. Physically disconnect line cords and other power cables when you are not working on live equipment. Use a lockout on circuit breakers. Double-check visually and with a meter to be absolutely sure power has been removed.

Interlocks — Unless specifically instructed by the manufacturer's procedures to do so, never bypass an interlock. This is rarely required except in troubleshooting and should only be done when absolutely necessary. Interlocks are there to protect you.

The One-Hand Rule — Keep one hand in your pocket while making any measurements on live equipment. The hand in your pocket removes a path for current to flow through you. It's also a good idea to wear shoes with insulating soles and work on dry surfaces. Current can be lethal even at levels of a few mA — don't tempt the laws of physics.

Test Equipment Rating — Be sure your test equipment is adequately rated for the voltages and power levels encountered in amplifiers! This is particularly important in handheld equipment in which there is no metal enclosure connected to an ac safety ground. Excessive voltage can result in a flashover to the user from the internal electronics, probes, or test leads, resulting in electric shock. Know and respect this rating.

If you are using an external high voltage probe, make sure it is in good condition with no cracks in the body. The test lead insulation should be in good condition — flexible and with no cracks or wire exposed. If practical, do not make measurements while holding the probe or meter. Attach the probe with the voltage discharged and then turn the power on. Turn power off and discharge the voltage before touching the probe again. Treat high voltage with care and respect!

Patience — Repairing an amplifier isn't a race. Take your time. Don't work on equipment when you're tired or frustrated. Wait several minutes after turning the amplifier off to open the cabinet — capacitors can take several minutes to discharge through their bleeder resistors.

A Grounding Stick — Make the simple safety accessory shown in the High Voltage section of the **Power Sources** chapter and use it whenever you work on equipment in which hazardous voltages have been present. The ground wire should be heavy duty (#12 AWG or larger) due to the high peak currents (hundreds of amperes) present when discharging a capacitor or tripping a circuit breaker. When equipment is opened, touch the tip of the stick to every exposed component and connection that you might come in contact with. Assume nothing — accidental shorts and component failures can put voltage in places it shouldn't be.

The Buddy System and CPR — Use the buddy system when working around any equipment that has the potential for causing serious injury. The buddy needn't be a ham, just anyone who will be nearby in case of trouble. Your buddy should know how to remove power and administer basic first aid or CPR.

CLEANLINESS

The first rule in taking good care of an amplifier is cleanliness. Amplifiers need not be kept sparkling new, but their worst enemy is heat. Excess heat accelerates component aging and increases stress during operation.

Outside the amplifier, prevent dust and obstructions from blocking the paths by which heat is removed. This means keeping all ventilation holes free of dust, pet hair and insects. Fan intakes are particularly susceptible to inhaling all sorts of debris. Use a vacuum cleaner to clean the amplifier and surrounding areas. Keep liquids well away from the amplifier.

Keep papers or magazines off the amplifier — even if the cover is solid metal. Paper acts as an insulator and keeps heat from being radiated through the cover. Amplifier heat sinks must have free air circulation to be effective. There should be at least a couple of inches of free space surrounding an amplifier on its sides and top. If the manufacturer recommends a certain clearance, mounting orientation or air flow, follow those recommendations.

Inside the amplifier, HV circuits attract dust that slows heat dissipation and will eventually build up to where it arcs or carbonizes. Use the vacuum cleaner to remove any dust or dirt. If you find insects (or worse) inside the amp, try to determine how they got in and plug that hole. Window screening works fine to allow airflow while keeping out insects. While you're cleaning the inside, perform a visual inspection as described in the next section.

Vacuuming works best with an attachment commonly known as a crevice cleaner. **Fig 26.23** shows a crevice cleaning attachment being used with a small paintbrush to dislodge and remove dust. The brush will root dust out of tight places and off components without damaging them or pulling on connecting wires. Don't use the vacuum cleaner brush attachment; they're designed for floors, not electronics. Some vacuums also have a blower mechanism, but these rarely

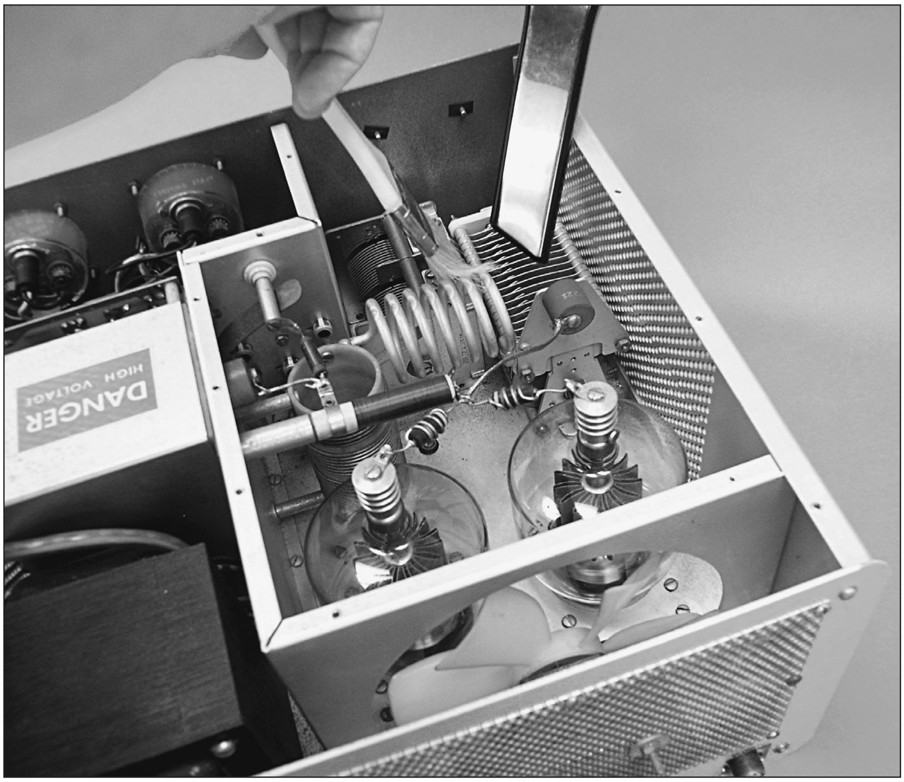

Fig 26.23 — A small paintbrush and a vacuum cleaner crevice attachment make dust removal easy.

have enough punch to clean as thoroughly as a brush. Blowing dust just pushes the dust around and into other equipment.

If you can't get a brush or attachment close enough, a spray can of compressed air will usually dislodge dust and dirt so you can vacuum it up. If you use a rag or towel to wipe down panels or large components, be sure not to leave threads or lint behind. Never use a solvent or spray cleaner to wash down components or flush out crevices unless the manufacturer advises doing so — it might leave behind a residue or damage the component.

VISUAL INSPECTION

Remove any internal covers or access panels and...stop! Get out the chicken stick (grounding stick), clip its ground lead securely to the chassis, and touch every exposed connection. Now, using a strong light and possibly a magnifier, look over the components and connections.

Amplifiers have far fewer components than transceivers, so look at every component and insulator. Look for cracks, signs of arcing, carbon traces (thin black lines), discoloration, loose connections, melting of plastic, and anything else that doesn't look right. This is a great time to be sure that mounting and grounding screws are tight. Does anything smell burnt? Learn the smells of overheated components. Make a note of what you find, repair or replace — even if no action is required.

ELECTRICAL COMPONENTS

Let's start with the power supply. There are three basic parts to amplifier power supplies — the ac transformer and line devices, the rectifier/filter, and the metering/regulation circuitry. (See the **Power Sources** chapter for more information.) Transformers need little maintenance except to be kept cool and be mounted securely. Line components such as switches, circuit breakers and fuses, if mechanically sound and adequately rated, are usually electrically okay, as well.

Rectifiers and HV filter capacitors require occasional cleaning. Look for discoloration around components mounted on a printed circuit board (PCB) and make sure that all wire connections are secure. HV capacitors are generally electrolytic or oil and should show no signs of leakage, swelling or outgassing around terminals.

Components that perform metering and regulation of voltage and current can be affected by heat or heavy dust. If there has been a failure of some other component in the amplifier — such as a tube — these circuits can be stressed severely. Resistors may survive substantial temporary overloads, but may show signs of overload such as discoloration or swelling.

Amplifiers contain two types of relays — control and RF. Control relays switch ac and dc voltages and do not handle input or output RF energy. The usual problem encountered with control relays is oxidation or pitting of their contacts. A burnishing tool can be used to clean relay contacts. In a pinch a strip of ordinary paper can be pulled between contacts gently held closed. Avoid the temptation to over-clean silver-plated relay and switch contacts. It is easy to remove contact plating with excessive polishing and while silver-plated relay and switch contacts may appear to be dark in color, oxidized silver (black) is still a good conductor. Once the silver's gone, it's gone; contact erosion will then be pervasive. If visual inspection shows heavy pitting or discoloration or resistance measurements show the relay to have intermittent contact quality, it should be replaced.

RF relays are used to perform transmit-receive (TR) switching and routing of RF signals through or around the amplifier circuitry. Amplifiers designed for full break-in operation will usually use a high-speed vacuum TR relay. Vacuum relays are sealed and cannot be cleaned or maintained. When you replace RF relays, use a direct replacement part or one rated for RF service with the same characteristics as the original.

Cables and connectors are subjected to heavy heat and electrical loads in amplifiers. Plastics may become brittle and connections may oxidize. Cables should remain flexible and not be crimped or pinched if clamped or tied down. Gently wiggle cables while watching the connections at each end for looseness or bending. Connectors can be unplugged and reseated once or twice to clear oxide on contact surfaces.

Carefully inspect any connector that seems loose. Be especially careful with connectors and cables in amplifiers with power supplies in separate enclosures from the RF deck. Those interconnects are susceptible to both mechanical and electrical stress and you don't want an energized HV cable loose on the operating desk. Check the electrical integrity of those cables and make sure they are tightly fastened.

As with relays, switches found in amplifiers either perform control functions or route RF signals. Adequately rated control switches, if mechanically sound, are usually okay. Band switches are the most common RF switch — usually a rotary phenolic or ceramic type. A close visual inspection should show no pitting or oxidation on the wiper (the part of the switch that rotates between contacts) or the individual contacts. Arcing or overheating will quickly destroy rotary switches. **Fig 26.24** is a photo of a heavy-duty band switch that has suffered severe damage from arcing. Slight oxidation is acceptable

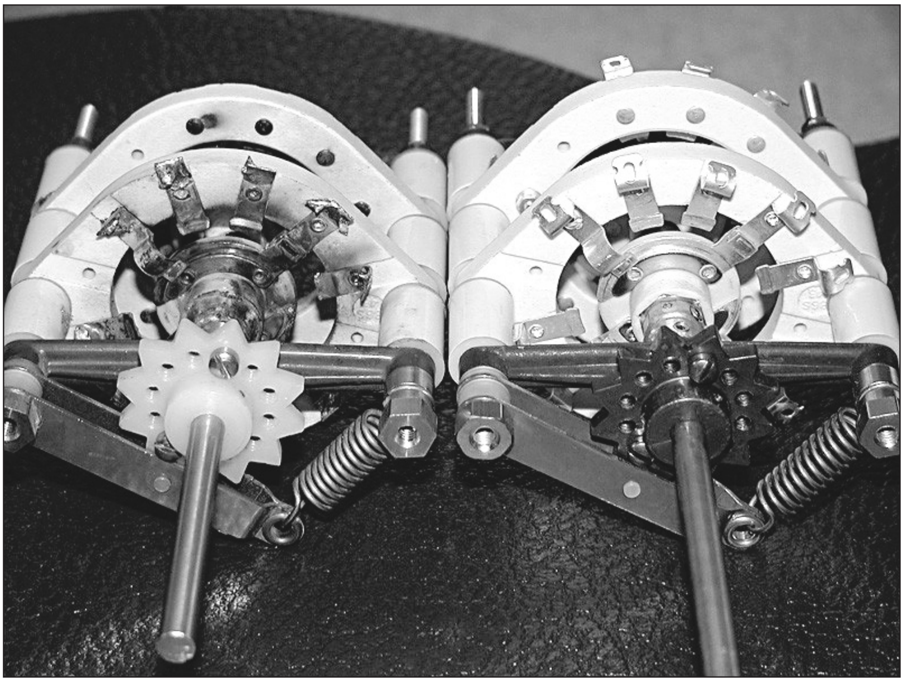

Fig 26.24 — The band switch section on the left clearly shows the signs of destructive arcing.

on silver-plated switches. Phosphor-bronze contacts can sometimes be cleaned with a light scrub from a pencil eraser, but plating can be easily removed, so use caution with this method and be sure to remove any eraser crumbs. Rotary switch contacts cannot be replaced easily although individual wafer sections may be replaced if an exact matching part can be obtained.

When replacing capacitors and resistors, be sure to use an adequately rated part. Voltage and power-handling ratings are particularly important, especially for components handling high RF currents. An RF tank capacitor replacement should be checked carefully for adequate RF voltage and current ratings, not just dc. HV resistors are generally long and thin to prevent arcing across their surfaces. Even if a smaller (and cheaper) resistor has an equivalent power rating, resist the temptation to substitute it. In a pinch, a series string of resistors of the appropriate combined value can be used to replace one HV unit. Don't use carbon resistors for metering circuits, use metal or carbon film types. The carbon composition types are too unstable.

If you are repairing or maintaining an old amplifier and manufacturer-specific parts are no longer available, the ham community has many sources for RF and HV components. Fair Radio Sales (**www.fairradio.com**) and Surplus Sales of Nebraska (**www.surplussales.com**) are familiar names. Hamfests and web sites often have amplifier components for sale. (See the **RF Power Amplifiers** chapter's sidebar on using surplus or used parts for amplifiers.) You might consider buying a non-working amplifier of the same model for parts.

TUBES

Good maintenance of tubes starts with proper operation of the amplifier. Follow the manufacturer's instructions for input drive levels, duty cycles, tuning and output power level. Frequently check all metered voltages and current to be sure that the tubes are being operated properly and giving you maximum lifetime. Penta Labs' "Tube Maintenance & Education" (**www.pentalaboratories.com/maintenance.asp**) is an excellent web page on maintaining power tubes.

The internal mechanical structures of tubes generally do not deal well with mechanical shock and vibration, so treat them gently. The manufacturer may also specify how the amplifier is to be mounted, so read the operating manual. Tubes generate a lot of heat, so it's important that whatever cooling mechanism employed is kept at peak efficiency. Airways should be clean, including between the fins on metal tubes. All seals and chimneys should fit securely and be kept clean. Wipe the envelope of glass tubes clean after handling them — fingerprints should be removed to prevent baking them into the surface. On metal tubes that use finger-stock contacts, be sure the contacts are clean and make good contact all the way around the tube. Partial contact or dirty finger stock can cause asymmetric current and heating inside the tube, resulting in warping of internal grids and possibly cause harmonics or parasitics.

Plate cap connections and VHF parasitic suppressors should be secure and show no signs of heating. Overheated parasitic suppressors may indicate that the neutralization circuit is not adjusted properly. Inspect socket contacts and the tube pins to be sure all connections are secure, particularly high-current filament connections. Removing and inserting the tubes once or twice will clean the socket contacts.

Adjustments to the neutralizing network, which suppresses VHF oscillations by negative feedback from the plate to grid circuit, are rarely required except when you are replacing a tube or after you do major rewiring or repair of the RF components. The manufacturer will provide instructions on making these adjustments. If symptoms of VHF oscillations occur without changing a tube, then perhaps the tube characteristics or associated components have changed. Parasitic oscillations in high-power amplifiers can be strong enough to cause arcing damage. Perform a visual inspection prior to readjusting the neutralizing circuit.

Metering circuits rarely fail, but they play a key part in maintenance. By keeping a record of normal voltages and currents, you will have a valuable set of clues when things go wrong. Record tuning settings, drive levels, and tube voltages and currents on each band and with every antenna. When settings change, you can refer to the notebook instead of relying on memory.

MECHANICAL

Thermal cycling and heat-related stresses can result in mechanical connections loosening over time or material failures. Switch shafts, shaft couplings and panel bearings all need to be checked for tightness and proper alignment. All mounting hardware needs to be tight, particularly if it supplies a grounding path. Examine all panel-mounted components, particularly RF connectors, and be sure they're attached securely. BNC and UHF connectors mounted with a single nut in a round panel hole are notorious for loosening with repeated connect/disconnect cycles.

Rubber and plastic parts are particularly stressed by heat. If there are any belts, gears or pulleys, make sure they're clean and that dust and lint are kept out of their lubricant. Loose or slipping belts should be replaced. Check O-rings, grommets and sleeves to be sure they are not brittle or cracked. If insulation sleeves or sheets are used, check to be sure they are covering what they're supposed to. Never discard them or replace them with improperly sized or rated materials.

Enclosures and internal shields should all be fastened securely with every required screw in place. Watch out for loosely overlapping metal covers. If a sheet metal screw

has stripped out, either drill a new hole or replace the screw with a larger size, taking care to maintain adequate clearance around and behind the new screw. Tip the amplifier from side to side while listening for loose hardware or metal fragments, all of which should be removed.

Clean the front and back panels to protect the finish. If the amplifier cabinet is missing a foot or an internal shock mount, replace it. A clean unit with a complete cabinet will have a significantly higher resale value, so it's in your interest to keep the equipment looking good.

SHIPPING

When you are traveling with an amplifier or shipping it, some care in packing will prevent damage. Improper packing can also result in difficulty in collecting on an insurance claim, should damage occur. The original shipping cartons are a good method of protecting the amplifier for storage and sale, but they were not made to hold up to frequent shipping. If you travel frequently, it is best to get a sturdy shipping case made for electronic equipment. Pelican (**www.pelican-shipping-cases.com**) and Anvil (**www.anvilsite.com**) make excellent shipping cases suitable for carrying amplifiers and radio equipment.

Some amplifiers require the power transformer to be removed before shipping. Check your owner's manual or contact the manufacturer to find out. Failure to remove it before shipping can cause major structural damage to the amplifier's chassis and case.

Tubes should also be removed from their sockets for shipment. It may not be necessary to ship them separately if they can be packed in the amplifier's enclosure with adequate plastic foam packing material. If the manufacturer of the tube or amplifier recommends separate shipment, however, do it!

CLEANING AND MAINTENANCE PLAN

For amateur use, there is little need for maintenance more frequently than once per year. Consider the maintenance requirements of the amplifier and what its manufacturer recommends. Review the amplifier's manuals and make up a checklist of what major steps and tools are required.

TROUBLESHOOTING

A benefit of regular maintenance will be familiarity with your amplifier should you ever need to repair it. Knowing what it looks (and smells) like inside will give you a head start on effecting a quick repair.

The following discussion is intended to illustrate the general flow of a troubleshooting effort, not be a step-by-step guide. Before starting on your own amplifier, review the amplifier manual's "Theory of Operation" section and familiarize yourself with the schematic. If there is a troubleshooting procedure in the manual, follow it. **Fig 26.25** shows a general-purpose troubleshooting flow chart. Do not swap in a known-good tube or tubes until you are sure that a tube is actually defective. Installing a good tube in an amplifier with circuit problems can damage a good tube.

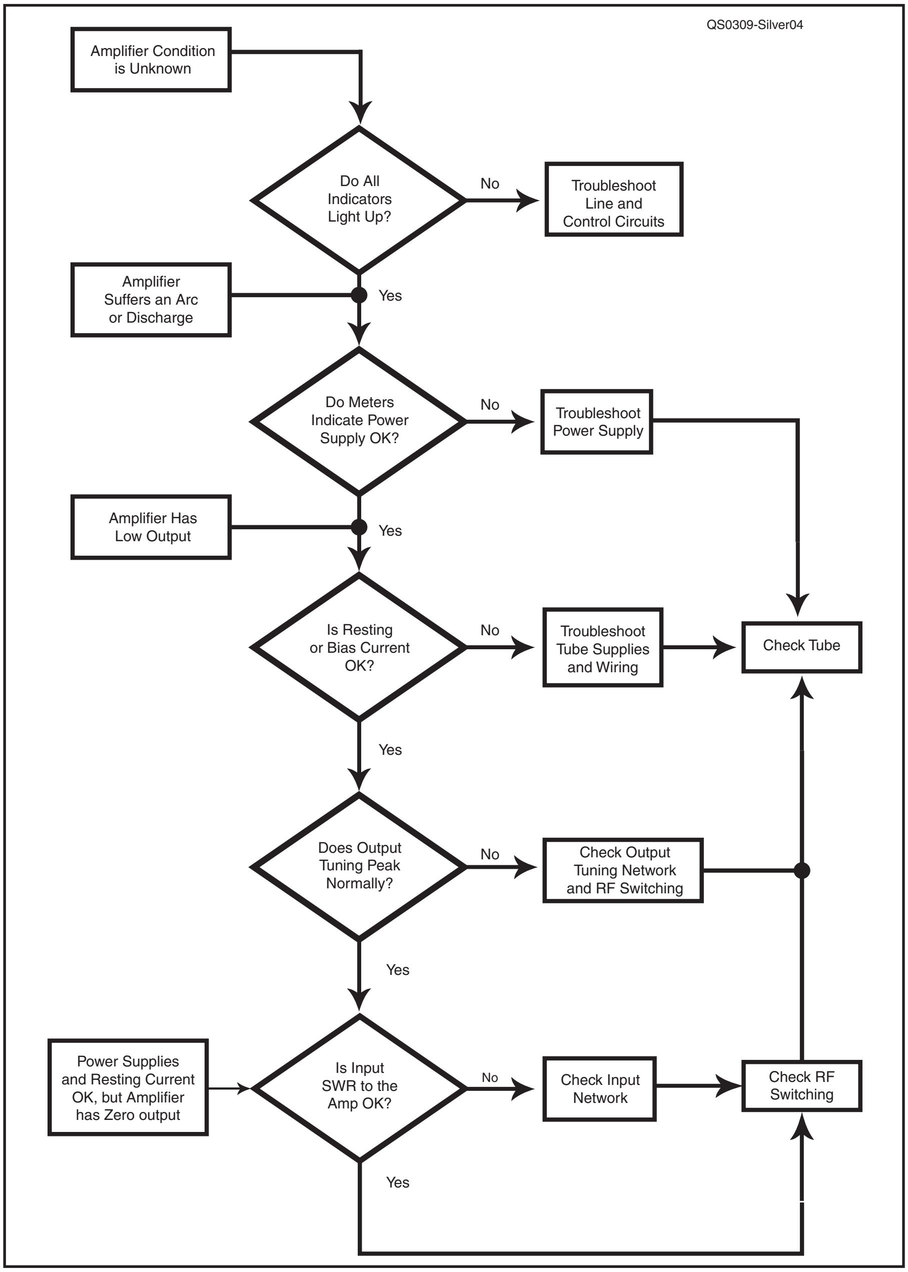

Fig 26.25 — This general-purpose flow chart will help identify amplifier problems. For solid-state units, substitute "Check Output Transistors" for "Check Tube."

Many "amplifier is dead" problems turn out to be simply a lack of ac power. Before even opening the cabinet of an unresponsive amplifier, be sure that ac is really present at the wall socket and that the fuse or circuit breaker is really closed. If ac power is present at the wall socket, trace through any internal fuses, interlocks and relays all the way through to the transformer's primary terminals. If the amplifier operates from 220/240-V circuits, remember that the white wire in such wiring is hot!

Hard failures in an HV power supply are rarely subtle, so it's usually clear if there is a problem. When you repair a power supply, take the opportunity to check all related components. If all defective components are not replaced, the failures may be repeated when the circuit is re-energized.

Rectifiers may fail open or shorted — test them using a DMM diode checker. An open

rectifier will result in a drop in the HV output of 50 percent or more but will probably not overheat or destroy itself. A shorted rectifier failure is usually more dramatic and may cause additional rectifiers or filter capacitors to fail. If one rectifier in a string has failed, it may be a good idea to replace the entire string as the remaining rectifiers have been subjected to a higher-than-normal voltage.

HV filter capacitors usually fail shorted, although they will occasionally lose capacitance and show a rise in ESR (equivalent series resistance). Check the rectifiers and any metering components — they may have been damaged by the current surge caused from a short circuit.

Power transformer failures are usually due to arcing in the windings, insulation failures, or overheating. HV transformers can be disassembled and rewound by a custom transformer manufacturer.

Along with the HV plate supply, tetrode screen supplies occasionally fail, too. The usual cause is the regulation circuit that drops the voltage from the plate level. Operating without a screen supply can be damaging to a tube, so be sure to check the tube carefully after repairs.

If the power supply checks out okay and the tube's filaments are lit, check the resting or bias current. If it is excessive or very low, check all bias voltages and dc current paths to the tube, such as the plate choke, screen supply (for tetrodes) and grid or cathode circuits.

If you do not find power supply and dc problems, check the RF components or RF deck. Check the input SWR to the amplifier. If it has changed then you likely have a problem in the input circuitry or one or more tubes have failed. Perform a visual check of the input circuitry and the band switch, followed by an ohmmeter check of all input components.

If input SWR is normal and applying drive does not result in any change in plate current, you may have a defective tube, tube socket or connection between the input circuits and the tube. Check the TR control circuits and relay. If plate current changes, but not as much as normal, try adjusting the output tuning circuitry. If this has little or no effect, the tube may be defective or a connection between the tube and output circuitry may have opened. If retuning has an effect, but at different settings than usual, the tube may be defective or there may be a problem in the tuning circuitry. A visual inspection and an ohmmeter check are in order.

The key to finding the trouble with your amplifier is to be careful and methodical, and to avoid jumping to false conclusions or making random tests. The manufacturer's customer service department will likely be helpful if you are considerate and have taken careful notes detailing the trouble symptoms and any differences from normal operation. There may be helpful guidelines on the manufacturer's web pages or from other Internet resources. Sometimes there is more than one problem — they work together to act like one very strange puzzle. Just remember that most problems can be isolated by careful, step-by-step tests.

26.10 Antenna Systems

This section is an abbreviated version of the Antenna System Troubleshooting chapter of the *ARRL Antenna Book* that was added to the 22nd edition. Because of the enormous variety of antenna systems, general guidelines must be presented, but the successful troubleshooting process usually follows a systematic approach just as for any other radio system.

26.10.1 Basic Antenna System Troubleshooting

Start with an inventory of the antenna system. Any of these can be the cause of your problem: supports, insulators, elements, feed point, balun (if any), feed line, grounding or transient protectors, impedance matching and switching equipment, RF jumper cables at any point. As with any troubleshooting process, be alert for mistaken or loose connections, loose or disconnected power and control cables, wires touching each other that shouldn't be, and so forth. Reduce the antenna system to the simplest system with the problem and it will likely look something like the system in **Fig 26.26**.

It is particularly important to remember that your station ground is often part of the antenna system. The length of the connection between the equipment ground bus and the ground rod is usually several feet at minimum and that can be an appreciable fraction of a wavelength on the higher HF bands. This can greatly affect tuning if there is common-mode current on the feed line or if a random-wire or end-fed type of antenna is being used. If touching equipment enclosures or the ground wire affects SWR or impedance readings, that will affect your antenna measurements as well.

DUMMY-LOAD TESTING

Begin by replacing components of your antenna system with a dummy load, starting at the output of the radio using a known-good jumper cable. Verify that the radio works properly into a 50 Ω load using a known-good directional wattmeter. Then move the dummy load to the output side of any antenna tuning or switching equipment, one component at a time until you have replaced the antenna feed line with the dummy load. If everything checks OK to this point, the problem is in the feed line or antenna. Don't forget to verify that the problem with the antenna is still present after each dummy load test. If the problem was a loose or intermittent connection, it is likely that swapping the dummy load in and out changed or eliminated the problem.

ANTENNA VISUAL INSPECTION

Now it is time to perform a visual inspection of the feed line and antenna itself. Start with the feed line connector at the last point where the dummy load was swapped in. Disassemble the connector and inspect it for damage from water or corrosion. If either are present, replace the connector and check the condition of the cable before proceeding. Note that if water can get into the cable at the antenna's elevated feed point, it is not unknown for it to flow downward through the braid both by gravity and by capillary action all the way to the shack! If the cable braid is wet at both ends, the cable must be replaced.

If you have a wire antenna, lower it and make a visual inspection of all the pieces.

- Cut away the waterproofing around the coax termination and inspect for water and/or corrosion.
- On the insulators at each end, there is no possibility of contact between the antenna wire and the supporting wire/ropes.
- If there are any splices in the wire elements, they are well crimped or soldered.
- At the center insulator, there is no possibility of contact between the element wires.
- At the balun or coax connection the element connections are soldered or firmly connected.

If you have a Yagi or vertical antenna, similar steps are required. Carefully check any feed point matching assembly, such as a gamma match, hairpin, or stub and make sure connections are clean and tight.

ANTENNA TEST

Assuming any mechanical problems have been rectified, proceed to retest the antenna and feed line. Replace the antenna with a dummy load and check the feed line loss with a wattmeter or antenna analyzer at the antenna end of the feed line. If the feed line checks out OK, the problem must be in the antenna. Reattach the feed line to the antenna and verify that the problem remains. Note that for wire antennas lowered to near ground level, the resonant point will change — this

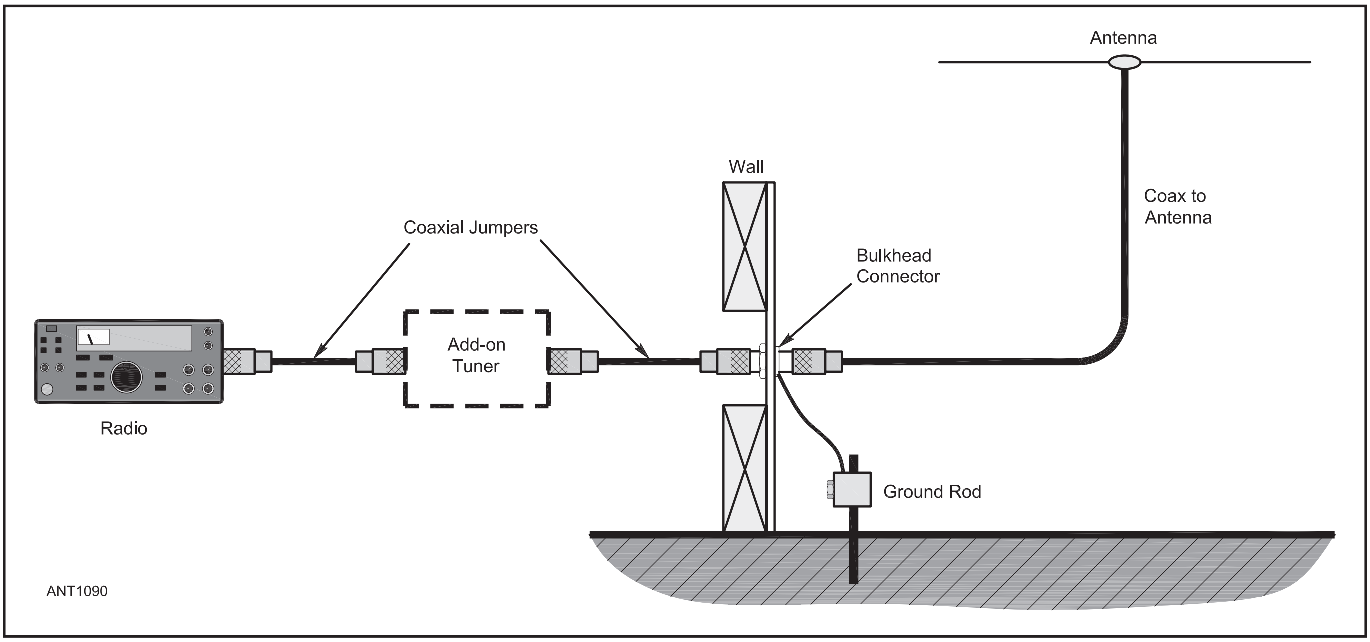

Fig 26.26 — A typical simple antenna system. An add-on antenna tuner is likely to be used if one is not built-in to the radio. More complex antenna systems have all of the same components plus some switching equipment.

is to be expected.

If the problem is still present, repeat the visual inspection at a closer level of detail. Check all dimensions and connections. Double-check any telescoping sections of tubing, transmission line stubs, in-line coax connectors, clamped connections between wires and between wires and tubing. If possible, give joints and connections a good shake while watching for intermittent readings on the wattmeter or antenna analyzer. If you cannot see inside a component or assembly, perform resistance tests for continuity. Remember to identify your signals since you are testing on the air at this point in the process.

The next step is to reinstall or raise the antenna at least ¼-wavelength off the ground and verify that the problem remains. If you have repaired the antenna, perform a re-check at this point to be sure everything is in good working order before returning the antenna to full height. Once you have re-installed the antenna, including full weatherproofing of any coaxial cable terminations or connectors, record in the shack notebook your measurements of the antenna along with what the problem was discovered to be and how you repaired it.

AM Broadcast Interference to Antenna Analyzers

Living or testing within a couple of miles of an AM broadcast station can create a lot of problems for the sensitive RF detectors in portable antenna analyzers. This type of RFI usually appears as values of SWR and impedance that don't change with frequency or that change in unexpected ways or an upscale meter reading that varies with the station modulation. The analyzer SWR reading will not agree with SWR measured by using a directional wattmeter and more than a few watts of power. The solution is sometimes to use a broadcast-rejection filter (available from analyzer manufacturers) although this tends to color measurements a bit and typically can't be used for measurements on 160 meters because it is so close to the AM broadcast band. In cases where the station is nearby or on 160 meters, directional wattmeters or analyzers with narrow-band tuned inputs must be used.

26.10.2 General Antenna System Troubleshooting

Think of the following topics as a kind of toolbox for troubleshooting. Many of them assume you are testing some type of Yagi or other beam antenna, but the general guidelines apply to all types of antennas

It is important to remember this simple rule for adjustments and troubleshooting: Do the simplest and easiest adjustment or correction *first*, and only *one* at a time.

When making on-air comparisons, select signals that are at the margin and not pushing your receiver well over S9 where it can be difficult to measure differences of a few dB. Terrain has a lot to do with performance as well. If you are comparing with a large station, keep in mind that its location was probably selected carefully and the antennas were placed exactly where they should be for optimum performance on the property.

TEST MEASUREMENTS

A) Test the antenna at a minimum height of 15 to 20 feet. (See **Fig 26.27**.) This will move the antenna far enough away from the ground (which acts to add capacitance to the antenna) and enable meaningful measurements. Use sawhorses *only* for construction purposes.

- 15 to 20 feet above ground does not mean 5 feet above a 10 to 15 foot high roof, it means above ground with nothing in between;
- Antenna resonant frequency will shift upward as it is raised;
- Feed point impedance will change with a change in height and this applies to both horizontal and vertical antennas;
- Some antennas are more sensitive to proximity to ground than others;
- Some antennas are more sensitive to nearby conductive objects (such as other antennas) than others.

B) Aiming the antenna upward with the reflector on the ground might coincide with some measurements on rare occasions, but there are no guarantees with this method. The reflector is literally touching a large capacitor (earth) and the driver element is very close,

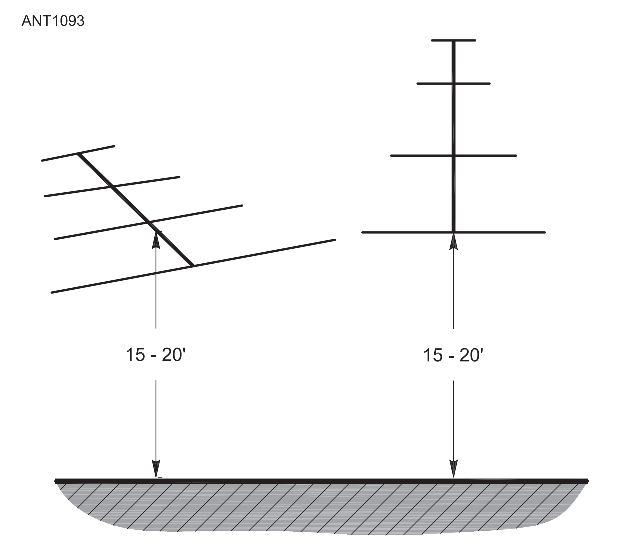

Fig 26.27 — When testing a Yagi or quad antenna, make sure it is at least 15 to 20 feet above ground. If oriented vertically, the reflector should be the closest to ground. Performance will still change as the antenna is raised.

too. Raise the antenna at least 15 to 20 feet off the ground.

C) When using a hand-held SWR analyzer you are looking for the dip in SWR, not where the impedance or resistance meter indicates 50 Ω. (Dip = frequency of lowest SWR value, or lowest swing on the meter.) On the MFJ-259/269 series, the left-hand meter (SWR) is the one you want to watch, not the right-hand meter (Impedance).

D) Does the SWR and frequency of lowest dip change when the coax length is changed? If so, the balun might be faulty, as in not isolating the load from the coax feed line.

Additionally, with an added length of coax and its associated small (hopefully small) amount of loss :

• The value of SWR is expected to be lower with the additional coax and,

• The width of the SWR curve is expected to be wider with the additional coax , when measured at the transmitter end of the coax.

E) Be sure you are watching for the right dip, as some antennas can have a secondary resonance (another dip). It is quite possible to see a Yagi reflector's resonant frequency, or some other dip caused by interaction with adjacent antennas.

MECHANICAL

A. Are the dimensions correct? Production units should match the documentation (within reason). When using tubing elements, measure each *exposed* element section during assembly and the element *half-length* (the total length of each half of the element) after assembly. Measuring the entire length is sometimes tricky, depending on the center attachment to the boom on Yagis, as the element can bow, or the tape might not lay flat along the tubing sections. Self-designed units might have a taper error.

B. Making the average taper diameter larger will make the equivalent electrical element longer. This makes the antenna act as if the physical element is too long.

C. Making the average taper diameter smaller will make the equivalent electrical element shorter. This makes the antenna act as if the physical element is too short.

D. If the element is a mono-taper (tubing element is the same for the entire length), larger diameter elements will be physically shorter than smaller diameter mono-taper elements to give the same electrical performance at the same frequency.

E. The type of mounting of the element to the boom affects the element length, whether it is attached directly to the boom, or insulated from the boom. Incorrect mounting/mounting plate allocation will upset the antenna tuning:

• A mounting plate 4 × 8 inches has an equivalent diameter of approximately 2.5 inches and 4 inches in length for each element half.

• A mounting plate that is 3 × 6 inches has an equivalent diameter of about 1.8 inches and a length of 3 inches for each element half.

• The mounting plate equivalent will be the first section in a model of the element half.

F. In a Yagi, if the elements are designed to be touching, are the elements touching the boom in the correct locations?

G. In a Yagi, if the elements are designed to be insulated, are the elements insulated from the boom in the correct locations?

H. The center of hairpin matching devices (i.e. on a Yagi) can be grounded to the boom .

I. The boom is neutral, but it is still a conductor! The center of a dipole element is also neutral and can be touched while tuning without affecting the reading. With a hairpin match , the center of the hairpin can also be touched while tuning and touching the whole hairpin might not affect the readings much at all.

PROXIMITY

A. What else is near-by (roof, wires, guy lines, gutters)? If it can conduct at all, it can and probably will couple to the antenna!

B. Does the SWR change when the antenna is rotated? If so, this indicates interaction. Note that in some combinations of antennas, there can be destructive interaction even if the SWR does not change. Computer models can be useful here.

C. What is within ¼ wavelength of the antenna? Imagine a sphere (like a big ball) with the antenna in question at the center of the sphere, with the following as a radius, depending on frequency. Think in three dimensions like a sphere — up and down and front and rear. Any resonant conductor (antenna or not) with the following radii will couple to and probably affect the antenna you are testing or installing.

160 meters = 140 feet
80 meters = 70 feet
40 meters = 35 feet
20 meters = 18 feet
15 meters = 12 feet
10 meters = 9 feet

D. Interaction occurs whether or not you are transmitting on the adjacent antennas. When receiving, it simply is not as apparent as when transmitting.

E. Wire antennas under a Yagi can easily affect it. This includes inverted V dipoles for the low bands and multi-band dipoles. The wire antennas are typically for lower frequency band (s) and will not be affected by the Yagi(s), as the Yagis are for the higher bands.

FEED SYSTEM

The feed system includes:

• the feed line,

• switching mechanisms,

• pigtails from the feed point on the antenna to the main feed line or switch and,

• all feed lines inside the radio room.

The feed system is the *entire connection* between the radio and the feed point of the antenna.

A. Is the feed line (coax) known to be good? (Start with the easiest first.) Check the dc resistance across the cable with the far end open and shorted. Is there water in the coax? This can give strange readings, even frequency-dependent ones. If there is any question, swap the feed line for a known good one and re-test.

B. Are the connectors installed properly? Has a connector been stressed (pulled)? Is the rotation loop done properly to not stress the coax? Is it an old existing loop or a new one? Usually it's alright if new. Type N connectors (especially the older type) are prone to having the center conductor pull out due

to the weight of the coax pulling down on the connector. Connectors are easy to do, using the right technique.

C. Is there a barrel connector (a PL-258 dual-SO-239 adapter) in the feed line anywhere? Has a new or different barrel been inserted? These are a common failure point, even with new barrels. The failures range from micro-bridges across the face of the barrel shorting out the center and shield, to resistance between the two ends of the barrel. Have the new barrels been tested in a known feed system? Always test them before installing. Use only quality RF adapters as these are common system failure points.

D. Is the coax intact and not frayed such that the shield can come into contact with anything? This can cause intermittent problems as the coax shield touches the tower, such as on rotation loops and coax on telescoping towers.

E. Is the tuner OFF on the radio? This is often overlooked when adding a new antenna.

F. Are there any new devices in the line? It might be a good idea to remove everything but the essential items when troubleshooting.

G. Is there a remote antenna switch? Swap to another port.

H. Is there a low pass filter in the line? The filter can be defective, especially on 10 meters, causing strange SWR readings

26.11 Repair and Restoration of Vintage Equipment

When purchasing a classic receiver or transmitter, unless you absolutely know otherwise, assume the radio will need work. Often you can get a top-of-the-line radio needing a bit of repair or clean-up inexpensively. Don't worry — these radios were designed to be repaired by their owners — and curiously, except for cosmetic parts such as cabinets and knobs, parts are much easier to find for 60-year-old radios than a 20-year-old imported transceiver!

Chances are the radio has gone for years without use. Even if it has been recently used, don't completely trust components that might be 60 or more years old. Don't start by plugging in your new acquisition! To do so might damage a hard-to-replace power transformer, or cause a fire.

Instead, if the radio didn't come with its owner's manual, get one. Several *QST* vendors sell old manuals in good condition. K4XL's Boat Anchor Manual Archive (**www2.faculty.sbc.edu/kgrimm/boatanchor**) is probably *the* best free resource for these manuals. Armed with the manual, remove the radio from its cabinet. You very likely will find evidence of unsightly repairs, modifications, or even dangling wires. While modifications aren't necessarily bad, they can certainly add some drama to any necessary subsequent troubleshooting. It's up to you to reverse or remove them.

Another option for working with vintage equipment is to refer to editions of the *ARRL Handbook* published around the time that the equipment was in common use. The circuit design and construction practices described in the *Handbook* are likely to be representative of those in the radio and may provide guidance for troubleshooting, repair, and adjustment. Similarly, the troubleshooting sections and chapters in previous editions provide valuable guidance for working with equipment of the same or earlier vintages.

26.11.1 Component Replacement

Correct any obvious problems such as dangling components. Replace the line cord with a three-wire, grounded plug, if not a transformerless "ac/dc" type as discussed below. If the radio is one with a live chassis, you should operate it from an isolation transformer for safety. If you don't have an isolation transformer, use a voltmeter to determine the orientation of the ac plug that places the chassis at ground potential. Avoid teaching touching the chassis and do not use knobs with set screws that contact metal control shafts. It's also a good idea to add a fuse, if the radio doesn't originally have one. Are we ready to give it the smoke test? Not so fast!

CAPACITOR RATINGS

Obviously, aged components deteriorate and capacitors are particularly prone to developing leakage or short-circuits with age. There are as many opinions on capacitor replacement as there are radio collectors, but *at the very least* you should replace the electrolytic filter capacitors. Here's why: they *will* short circuit sometime, and when they do, they'll probably take the rectifier tube and the power transformer with them. Modern high voltage electrolytic capacitors are reliable and much smaller than their classic counterparts. Old paper-wax and black plastic tubular capacitors should also be replaced. Again, a short circuit in one of them could take out other components, too. Modern film capacitors of the appropriate voltage are great replacements. Opinions vary as to whether all should be replaced, but replacements are cheap and you have the radio apart now, so why not? If keeping the original components is important, follow the procedure for using a variable transformer to reform electrolytics as described below.

You can mount the new capacitors under the chassis by mounting a new terminal strip (do *not* just wire them to the old capacitor terminals), you can re-stuff an old electrolytic capacitor's can with new capacitors, or you can buy a new can from places such as **www.hayseedhamfest.com** or Antique Electronics Supply (**www.tubesandmore.com**). In any event, follow the manufacturer's schematic — don't assume that the – (minus) end of the capacitor goes to ground, as in some radios the ground path is through a resistor so as to develop bias for the audio output stage or RF gain circuit. Observe the polarity or you'll soon be cleaning up a stinky mess!

TESTING OLD CAPACITORS

All capacitors have a voltage rating written on the side of the cap unless it is a small disc. Surplus stores often have bins full of capacitors of unmarked voltage rating. Don't assume they are a high enough voltage to use — check them with a capacitor checker. There are many models out there by Knight Kit, Lafayette, Sencore, and Eico, but the best were the Heathkit IT-11 or IT-28. They are basically the same model but different colors. Both use a 6E5 Magic Eye tube to indicate the status of the capacitor. A selectable voltage from 3 to 600 V dc can be applied to check for leakage and operation. These are good for small disc or paper caps and large electrolytics.

Take the unknown voltage cap and place it in the test terminals. Advance the voltage control from minimum until the eye tube shows it breaking down. You now know what voltage it is good to.

If the capacitor tests good through the 600 V dc range, it probably is a 1000 V dc capacitor. It is best, though, to know for sure the rating of the cap. In tube equipment, most capacitors should be 500 or 1000 V rated. Mouser (**www.mouser.com**) and Digikey (**www.digikey.com**) do still sell caps for

those voltage ranges, but they have become very expensive. You could also find new old stock (NOS) capacitors of the correct voltage rating at surplus stores.

REFORMING ELECTROLYTIC CAPACITORS

The best idea is to replace old electrolytic capacitors with a new unit. They are available cheaply in the voltage ranges required and more compact and reliable than the original electrolytic caps. If necessary, however, old electrolytics can often be revived by reforming the dielectric using a capacitor checker.

Disconnect the wires attached to the capacitor under test and connect it to the capacitor checker. Start at the lowest voltage rating and let it charge up the capacitor. You will know when it is charged by viewing the eye tube: if it is wide open, the cap is charged; if it is closed, the capacitor is either shorted or still charging. Advance gradually to the next voltage rating and wait until the eye fully opens—take plenty of time for the capacitor to stabilize. Continue on through the voltage ranges; each time it will take longer for the eye to open. The dielectric is being reformed. Finally, when you reach the voltage range of the capacitor and the eye is fully open, the cap has been fully revived and is ready for use.

The same process can be performed with a variable autotransformer (Variac) by advancing it a few volts at a time over several hours, but that is a coarse and unreliable process. A diode must be placed in series with the transformer to convert the ac voltage to dc. Monitor the voltage across the capacitor with a meter. If it suddenly jumps to zero, the capacitor has shorted and is now useless. Usually the capacitor can be revived successfully and will work just fine.

RESISTORS

Over time, carbon resistors in older radios can change value significantly, which can affect circuit operation. Disconnect one end of the questionable resistor and measure it with an accurate ohmmeter. If it is out of tolerance, replace it. Most resistors in the tube era were ½ W or greater. Most circuits today use ¼ W or smaller resistors, which will not dissipate the power tubes produce.

Carbon composition resistors are becoming rarer but there are still ample quantities of NOS in surplus stores. Be careful about power rating. Use metal oxide resistors if needed. Remember that wirewound resistors are very inductive and not good for RF circuits. They are excellent for power supply circuits and are usually found in the 1 to 25 W range.

REPLACING DIODES

Many old tube radios use rectifier tubes. It is not a good idea to replace these with solid-state rectifiers, as a shorted diode can take out the transformer. Selenium rectifiers, however, are good candidates to replace with a silicon diode. The 1N400x series of diode are usually fine for use and very cheap. For higher voltage supplies, be sure to use 1N4007 or higher rated diodes. This may result in higher ouput voltage from the supply. Add a series dropping resistor if necessary to reduce voltage.

TRANSFORMER REPLACMENT

The best bet is to find another radio of the same variety from which you can harvest the transformer. This is especially common in transmitters like the Heathkit DX-35 and DX-40 which frequently had transformers fail. Replacement transformers are generally no longer available. Some companies will rewind transformers, but that is usually prohibitively expensive. Output voltages are quite critical in the design of tube radios, so it is not a good idea to replace a 400 V ac transformer with a 600 V ac unit. It may be best to find a donor radio for a replacement transformer.

WIRE REPLACEMENT

Power cords should be replaced at the first sign of hardening and cracking. It is often a good idea to replace the two-wire power cords with three-wire cords, but this *cannot* be done on ac/dc transformerless radios in which one side of the ac line is connected directly to the chassis! Those must retain the two-wire cords. As noted previously, operating these radios with an isolation transformer is the safest option. If replacing the cord with a two-wire version, the neutral (larger blade) must be connected to the chassis.

Pre-WWII vintage radios often used a cotton covered power cord. To keep the radio as authentic as possible, cotton covered power cords and matching plugs can be found at suppliers such as Antique Radio Supply.

Many early radios had a two-pin power plug with fuses in the plug (the radio has no internal fusing). These are made by Elmeco and are still available (check eBay). Standard 3AG type fuses go in the power plug. Usually a 1 or 2 A fast-blow fuse will work fine except for a higher powered transmitter.

For using PVC-covered wire with terminal strips, solid wire is easier to attach before soldering than stranded wire, although stranded is very usable. You can also use Teflon covered wire that doesn't burn when the soldering iron hits the insulation.

TUBE REPLACEMENT

The sidebar "Using a Tube Tester" explains what a tube tester does. Watch swap meets and garage sales for tube substitution books. Many tubes are interchangeable or similar in purpose. Be sure to document any tube substitutions you make on a vintage radio. Remember that a new tube in the circuit may require re-peaking of the tuned circuits associated with it.

If a tube has a loose tube cap on top, you can easily repair it. Unsolder the cap and make sure that ample wire is still coming from the tube glass envelope. The tube cap should have a tiny hole in the center of the top which the wire will pass through. Mix a small amount of JB Weld epoxy (**www.jbweld.com**) and glue the tube cap back in place. Make sure the wire is sticking out of the hole. After the epoxy has hardened, solder the wire back onto the tube top. Don't let a loose tube cap break it off.

One might be anxious to wipe off the tube and clean it up. Be careful, as you might wipe off the tube number, and then you won't have any idea what the tube is. Many tubes have been lost because they have become unidentifiable. If you do decide to clean up the tube, make sure you steer well clear of the tube number.

Using a Tube Tester

Vacuum-tube testers are scarce but can be located through antique or vintage radio associations, audiophile groups, and sellers of tubes.

Most simple tube testers measure the cathode emission of a vacuum tube. Each grid is shorted to the plate through a switch and the current is observed while the tube operates as a diode. By opening the switches from each grid to the plate (one at a time), we can check for opens and shorts. If the plate current does not drop slightly as a switch is opened, the element connected to that switch is either open or shorted to another element. (We cannot tell an open from a short with this test.) The emission tester does not necessarily indicate the ability of a tube to amplify.

Other tube testers measure tube gain (transconductance). Some transconductance testers read plate current with a fixed bias network. Others use an ac signal to drive the tube while measuring plate current.

Most tube testers also check inter-element leakage. Contamination inside the tube envelope may result in current leakage and shorts between elements. The paths can have high resistance, and may be caused by gas or deposits inside the tube. Tube testers use a moderate voltage to check for leakage. Leakage can also be checked with an ohmmeter using the ×1M range, depending on the actual spacing of tube elements.

Tube sockets and tube pins easily become oxidized which result in radios not working or being intermittent. It is a good idea to pull each tube and spray the socket with DeoxIT or tuner cleaner. Re-insert the tube and wiggle it around in the socket to rub away any oxidation remaining.

REMOVING AND REPLACING COMPONENTS

Replacing capacitors and/or other components isn't difficult, unless they are buried under other components. The Hallicrafters SX-28 and SX-42 receivers are examples of receivers that have extremely difficult-to-reach components. There are different schools of thought on the proper component replacement method. You can use solder wick and/or a desoldering tool to remove the solder from a terminal, unwrap the wires, and install the new component by wrapping the lead around the terminal and soldering it securely. The proponents of this method point out that this is the preferred military and commercial method. I find it often will needlessly damage other components such as tube sockets and create solder droplets inside of the radio.

Back in the day, radio repairmen clipped out a component leaving a short stub of wire, made little coils in the new lead, then soldered the coiled lead to the old stub. This is a much faster, easier and neater method. Refer to books and websites on repairing vintage equipment for other useful tips and tricks.

26.11.2 Powering Up the Equipment

Get out your volt-ohm meter and measure the resistance from the B+ line to ground. Filter capacitors will cause an initial low-resistance reading that increases as the capacitors charge. If the resistance stays low or does not increase beyond tens of kΩ, find the short circuit before you proceed. Now it's time to plug in the radio. It's best to use a variable transformer such as a Variac and ramp up the voltage slowly, or use a "dim bulb tester" (a 100 W light-bulb wired in series with one leg of the ac power). Turn on the radio, and watch for any sparking, flashing or a red glow from the plates of the rectifier tube, or smoke. If any of these occur, immediately remove power and correct the problem. Observe that the tube filaments should light (although you won't see the glow from metal tubes, you should be able to feel them warm up). Again, any tubes that fail to light should be replaced before you continue.

Now hook up a speaker and antenna, and test the radio. With any luck you'll be greeted by a perfectly-performing radio. Seldom, however, is that the case. You may encounter any number of problems at this point. Dirty bandswitches and other controls manifest themselves by intermittently cutting out; they can be cleaned by DeoxIT contact cleaner applied with a cotton swab (don't spray the switch directly!). Scratchy volume or RF gain controls can be cleaned with some DeoxIT; in some cases you might need to remove the control and uncrimp the cover to reveal the carbon element inside.

If a receiver is totally dead at this point but the filaments and dial lights are lit, double-check to see that the Receive-Standby switch is in the receive position, and any battery plug or standby switch jumpers (as described in the manual) are in their correct place.

Although comprehensive troubleshooting is covered elsewhere in this chapter, the next step is comparing voltages with those stated in the user manual. If the manual doesn't have a voltage table denoting the expected voltage at each tube pin, expect between 200-350 V at the tube plate terminals, a few volts at the cathode (unless it's directly grounded), 70-200 V at the screen, and slightly negative voltage at the grid. If you're faced with this situation and a newcomer to troubleshooting vintage gear, help can be found at **http://amfone.net**, **www.antiqueradios.com**, or other forums that cater to boat-anchors and/or vintage radio repair and restoration.

26.11.3 Alignment

Over the years hams have been cautioned that alignment is usually the *last* thing that should be attempted to repair a radio. In general this is true — but it's also a certainty that a 50 year old radio *will* need alignment in order for it to perform at its best. In any case, replace the capacitors and any other faulty components before you attempt alignment — it'll never be right if it still has bad parts! You'll need a good signal generator and a volt-ohm-meter or oscilloscope. Follow the manufacturer's instructions, and with care you'll be rewarded with a radio that performs as good as it did when it was new.

RECEIVER ALIGNMENT

One last caution — alignment should not be attempted by the novice technician or if you do not have the proper equipment or experience. That said alignment may be justified under the following conditions:

- The set is very old and has not been adjusted in many years.
- The circuit has been subject to abusive treatment or environment.
- There is obvious misalignment from a previous repair.
- Tuned-circuit components or crystals have been replaced.
- An inexperienced technician attempted alignment without proper equipment.
- There is a malfunction, but all other circuit conditions are normal. (Faulty transformers can be located because they will not tune.)

Even if one of the above conditions is met, do not attempt alignment unless you have the proper equipment. Receiver alignment should progress from the detector to the antenna terminals. When working on an FM receiver, align the detector first, then the IF and limiter stages and finally the RF amplifier and local oscillator stages. For an AM receiver, align the IF stages first, then the RF amplifier and oscillator stages.

Both AM and FM receivers can be aligned in much the same manner. Always follow the manufacturer's recommended alignment procedure. If one is not available, follow these guidelines:

1. Set the receiver RF gain to maximum, BFO control to zero or center (if applicable to your receiver) and tune to the high end of the receiver passband.
2. Disable the AGC.
3. Set the signal source to the center of the IF passband, with no modulation and minimum signal level.
4. Connect the signal source to the input of the IF section.
5. Connect a voltmeter to the IF output.
6. Adjust the signal-source level for a slight indication on the voltmeter.
7. Peak each IF transformer in order, from the meter to the signal source. The adjustments interact; repeat steps 6 and 7 until adjustment brings no noticeable improvement.
8. Remove the signal source from the IF section input, reduce the level to minimum, set the frequency to that shown on the receiver dial and connect the source to the antenna terminals. If necessary, tune around for the signal — if the local oscillator is not tracking, it may be off.
9. Adjust the signal level to give a slight reading on the voltmeter.
10. Adjust the trimmer capacitor of the RF amplifier for a peak reading of the test signal. (Verify that you are reading the correct signal by switching the source on and off.)
11. Reset the signal source and the receiver tuning for the low end of the passband.
12. Adjust the local-oscillator padder for peak reading.
13. Steps 8 through 11 interact, so repeat them until the results are as good as you can get them.

26.11.4 Using Vintage Receivers

Connect a speaker, preferably the same impedance as the output impedance of the receiver. Some receivers have a 600 Ω and 3.2- or 4 Ω output. An 8 Ω speaker is fine — connect it to the low impedance output. Do not operate the receiver without a speaker, however, as the audio output transformer could be damaged by high voltage transients

with no load. Alternatively, plug in a pair of headphones, keeping in mind that old receivers usually have high impedance headphone outputs and new headphones are usually low impedance. They'll work fine, but the volume may be considerably lower with the newer headphones.

If you're going to use the receiver in conjunction with a transmitter, you need to be able to mute the receiver while you're transmitting — otherwise, you'll end up with copious feedback from the receiver. Most receivers have mute terminals — some mute with a closed switch, others mute on open. Figure out which method your receiver and transmitter use. You'll need a relay if the receiver mute arrangement doesn't match that of the transmitter.

Some receivers — such as the older Hammarlund Super Pros and pre-WWII Hallicrafters models — use the mute terminals to open the B+ when putting the receiver in standby mode. This is extremely dangerous with 300 V or so on exposed terminals! An easy modification will save you from an almost certain shock. Open up the receiver and remove the wires from the standby terminals. Solder them together and insulate the connection with electrical tape or a wire nut. Better, solder them to an unused, ungrounded terminal if there's one handy. Next, examine the RF gain control and notice that one terminal is probably grounded. Cut this wire and solder a 47 kΩ resistor between ground and the RF gain control terminal. Connect a pair of wires from the terminals of the mute connection across the 47 kΩ resistor just installed. Now, with the mute terminals open the RF gain is all the way down so the receiver is essentially muted. Short the terminals to receive. The voltage here is low and not dangerous.

Next, connect an antenna and antenna relay in the same manner and tune the bands. You'll find that the best fidelity from the receiver occurs at its maximum bandwidth. The crystal filter, if fitted, can help notch out heterodynes as can tuning the receiver slightly higher or lower. The bandspread control can be used to fine tune. Now, just enjoy using your classic, vintage equipment!

26.11.5 Plastic Restoration

Sometimes an old radio has a meter lens or dial face that is badly damaged. If it is cracked, there isn't much you can do but find a replacement. If it is just scratched, you have a good chance at fully restoring it.

First, remove the meter lens from the meter movement if possible. Most just snap on. To avoid damaging the very delicate needle and meter movement, place it in a protected area and be sure metal filings cannot get to the movement's magnet.

Make sure the scratch hasn't gone all the way though the plastic to become a crack, although even a deep scratch can be buffed out. You will need various grades of wet/dry sandpaper. Obtain sheets of 320, 400 and 600 grit (600 is the finest). One sheet will last a long time. Cut a piece about ½ inch by 2 inches and fold it in half. Start with 320 and gently sand in *one* direction only, over the scratch. This is very tedious and will take a while before you sand away enough plastic to get through the scratch.

Once the scratch is removed, it is time to start reconditioning the plastic. Again sanding in one direction, use the 400 and finally the 600 to completely remove all traces of the earlier sanding scratches. The 600 should leave almost a powdered effect but the plastic will still be hazy and opaque. Sand a little more with the 600 just to be sure all traces of any sanding scratches are gone completely.

To remove the haze you will need a polishing compound called Novus #2 (**www.novuspolish.com** or hobby stores) and another compound called Novus #1, which is a plastic shiner and static remover. This will be important to remove the static on the meter cases when you finish. Static causes the needle to react strangely and erratically.

Start with just a drop of NOVUS #2 and a soft cloth such as the disposable shop towels found at auto parts stores for polishing. Cut a 2 inch by 3 inch piece and start polishing. Continue for a long time and bit by bit the haze will disappear — you will be left with a perfectly clear lens.

FRONT PANEL RESTORATION

The most important part of a radio restoration, cosmetically, is the front panel. The case should also look good, but the front panel is the highlight of the radio and needs the most attention. Usually, paint on a radio from the 50s and 60s is well oxidized and there may be some fine scratches as well.

Scratches can be touched up by using enamel model car paint. Buy a bottle of gloss white, gloss black, and the color closest to the panel you have. Into a small paper cup put a drop or two of the stock color. Using the white or the black, stirring in a small drop at a time, lighten or darken the color until it most closely matches the panel. Use a model paint brush with the finest tip you can find to fill just the scratch and not get it on the rest of the paint. Remove excess with a Q-tip. Let it dry completely.

Remove the panel completely, if possible, or at least remove all the knobs. You will work on them individually later. If the panel was originally a gloss panel, you are in luck. If it is a wrinkle finish or flat, this technique might not work for you — those will be addressed later.

Use the Novus #2 compound to remove a few microns of paint — just the oxidized layer. Place a drop on the panel, and with a soft cloth or shop towel, start working the Novus into the paint. You just want to remove the oxidation, so don't rub too hard. Be careful when working on paint that is a second layer above a base paint. It can be very thin and removed with the Novus. After a small amount of gentle polishing, get another cloth or towel and wipe off the panel which should appear just as it did when it came from the factory.

If your panel is a wrinkle finish, you cannot use the Novus. Use a gentle soapy type cleaner and carefully brush the ridges and peaks of the finish to remove layers of dirt and smoke. Sometimes cleaners like 409 and Simple Green will work very well, but be cautious that it doesn't take off the lettering. Be very carefully around the lettering. One way to work it in is with a plumber's acid brush with the bristles cut very short. The bristles will get down into the crevices of the wrinkle finish and clean it. Once the panel is clean, it can be shined up a bit with some WD-40. This also works very well on wrinkle finish cabinets. Just lightly brush it on and remove it with a rag. This can collect dust but gives a nice wet finish to the wrinkle finish paints.

KNOBS

Most knobs are plastic or have metal plates around the bottom. Use the Novus #2 to shine up the flat parts of the knob. Knobs with flutes on the sides are very tedious to clean, but look beautiful once restored. Take a fine pick and drag it down each flute to scrape out the accumulated dirt. Once cleaned, the Novus can be used to shine up the flutes as well. On knobs with metalized bases, the bases are also shined up with the Novus. Make sure you don't polish off any markings on the trim bases. Sometimes the knobs will have white or red lines in the tops. Those can be filled with model paint to restore them to full beauty.

HOLES IN FRONT PANELS

It may be most disconcerting to find someone has drilled a hole in the panel for one reason or another. Extra holes greatly devalue the rig because to properly restore it, you have to find a replacement panel. Panels with wrong holes can be salvaged with quite nice results by using JB Weld epoxy metal filler (**www.jbweld.com**).

First remove the panel. If the hole is a considerable distance from the other knobs, repairs can be done on the radio but it is not advised. You will need a special tape called Kapton tape. This is a high temperature polymide film tape that is widely available but not cheap. A little tape lasts a long time.

You will need a piece of tape slightly larger than the hole. Other types of tape may work

but won't give as smooth a finish. If the panel is wrinkle finished, you may want a rough finish tape such as masking tape. The key is a tight fit to the front of the panel. Place a piece of tape across the hole on the front of the panel and seal it securely all around the hole.

Lay the panel on a flat surface tape-down so the tape will be held flat and not bulge at all. Mix a suitable amount of the JB Weld epoxy and flow it into the hole from the rear of the panel. Stir it while it is still very wet and pliable to make sure no air bubbles are in the hole. Let it cure securely overnight so the hole will be filled and rock hard.

Flip the panel over and remove the tape. If you have secured the tape well enough, none of the epoxy will have been drawn out onto the front surface. There should be a flat filled area exactly level with the rest of the panel.

Now you can touch up the repaired hole with an exact match of spray paint. Mask off the rest of the panel so you don't get any on the lettering. You can also use the model paint method, described for scratch repair Once painted, the offending hole should be virtually invisible.

BROKEN PLASTIC

Sometimes a microphone or other item will have a chunk of the plastic broken out of it. It is most unsightly and usually is the reason for discarding the item. But, using our repair technology, it can be saved and fully restored as in this example of repairing a damaged microphone case. This procedure will work well on broken Bakelite cases, too.

Once again, we will use JB Weld Epoxy and Kapton tape. Remove the microphone elements and switch from the case along with the cord and anything else not plastic. Clean the area around the broken part well. With the Kapton tape, make a backing area on the inside of the case to form a backing for the epoxy. The tape will hold it well and not deform.

Mix some JB Weld and pour it into the space around the break. Fill *higher* than the surrounding plastic. This will be difficult as the fill area will not be level. It may take a couple of fills to build up the area high enough to build up past the level of the surrounding plastic. Once cured and very hard (wait at least 24 hours), you now can begin to file the epoxy. File it down until it is nearly level with the plastic and then switch to sandpaper. Carefully sand the epoxy so it is exactly flush with the original plastic, and make sure the shape is correct. You can always add more JB Weld if too much is filed off.

Once sanded flush, finish the sanding with fine sandpaper (400 and 600 grade). The JB Weld will shine just like the original plastic, but will be the wrong color. Spray paint the entire case with a color close to the original. Once painted, the repair will be virtually undetectable!

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Contents

Chapter 27

RF Interference

This chapter is a complete revision of the "Interference" chapter in editions prior to 2011. A team of knowledgeable experts supported the greatly expanded scope. The topics listed for each of these individuals represent only their primary area of contribution.

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Chapter 27 — CD-ROM Content

Supplemental Files

- "What To Do if You Have an Electronic Interference Problem" — *CEA Handbook*
- TV Channel, Amateur Band and Harmonic Chart

Projects

- "A Home-made Ultrasonic Power Line Arc Detector and Project Update" by Jim Hanson, W1TRC (SK)
- "A Simple TRF Receiver for Tracking RFI" by Rick Littlefield, K1BQT
- "Active Attenuator for VHF-FM" by Fao Eenhoorn, PAØZR (article and template)
- "Simple Seeker" by Dave Geiser, W5IXM
- "Tape Measure Beam for Power Line Hunting" by Jim Hanson, W1TRC (SK)

Amateurs live in an increasingly crowded technological environment. As our lives become filled with technology, every lamp dimmer, garage-door opener or other new technical "toy" contributes to the electrical noise around us. Many of these devices also "listen" to that growing noise and may react to the presence of their electronic siblings. The more such devices there are, the higher the likelihood that the interactions will be undesirable.

What was once primarily a conversation about "interference" has expanded to include power systems, shielding, intentional and unintentional radiators, bonding and grounding, and many other related topics and phenomena. These are all grouped together under the general label of *electromagnetic compatibility (EMC)*. The scope of EMC includes all the ways in which electronic devices interact with each other and their environment.

The general term for interference caused by signals or fields is *electromagnetic interference* or *EMI*. This is the term you'll encounter in the professional literature and standards. The most common term for EMI involving amateur signals is *radio frequency interference (RFI)* and when a television or video display is involved, *television interference (TVI)*. RFI is the term used most commonly by amateurs. Whether it's called EMI, RFI or TVI, unwanted interaction between receivers and transmitters has stimulated vigorous growth in the field of electromagnetic compatibility! (This chapter will use the term RFI to refer to all types of interference to or from amateur signals, except where noted.)

This chapter begins with an overview of dealing with interference and includes relevant FCC regulations. This section is an excellent resource when you are confronted with an interference problem and are wondering "What do I do now?" The information here is based on the experiences of ARRL Lab staff in assisting amateurs with RFI problems.

The second part of this chapter is a discussion on identifying and locating RFI-related noise and signal sources then presents some effective ways of resolving the problem. A glossary of RFI terminology concludes the chapter.

The material in this chapter may provide enough information for you to solve your problem, but if not, the ARRL website offers extensive resources on RF interference at **www.arrl.org/radio-frequency-interference-rfi**. Many topics covered in this chapter are covered in more detail in the *ARRL RFI Book* from a practical amateur perspective.

Throughout this chapter you'll also find references to "Ott," meaning the book *Electromagnetic Compatibility Engineering* by EMC consultant Henry Ott, WA2IRQ. EMC topics are treated in far greater depth in Ott's book than is possible in this *Handbook*. Readers interested in the theory of EMC, analysis of EMC mechanisms, test methodology and EMC standards can purchase a copy through the ARRL Publication Sales department or the ARRL website.

27.1 Managing Radio Frequency Interference

Sooner or later, nearly every Amateur Radio operator will have a problem with RFI, but temper your dismay. Most cases of interference can be cured! Before diving into the technical aspects of interference resolution, consider the social aspects of the problem. A combination of "diplomacy" skills and standard technical solutions are the most effective way to manage the problem so that a solution can be found and applied. This section discusses the overall approach to solving RFI problems. Specific technical causes and solutions are described in subsequent sections.

27.1.1 Responsibility for Radio Frequency Interference

When an interference problem occurs, we may ask "Who is to blame?" The ham and the

other party often have different opinions. It is natural (but unproductive) to assign blame instead of fixing the problem.

No amount of wishful thinking (or demands for the "other guy" to solve the problem) will result in a cure for interference. Each party has a unique perspective on the situation and a different degree of understanding of the personal and technical issues involved. On the other hand, each party has certain responsibilities and should be prepared to address them fairly. (Given the realities of amateur operation, one of the parties is likely to be a neighbor to the amateur and so the term "neighbor" is used in this chapter.)

Always remember that every interference problem has two components — the equipment that is involved and the people who use it. A solution requires that we deal effectively with both the equipment and the people. The ARRL recommends that the hams and their neighbors cooperate to find solutions. The FCC also shares this view. It is important therefore to define the term "interference" without emotion.

27.1.2 Proper Station Operation

A radio operator is responsible for the proper operation of the radio station. This responsibility is spelled out clearly in Part 97 of the FCC regulations. If interference is caused by a spurious emission from your station, you must correct the problem there.

Fortunately, most cases of interference are not the fault of the transmitting station. If an amateur signal is the source of interference, the problem is usually caused by fundamental overload — a general term referring to interference caused by the intended, fundamental signal from a transmitter. If the amateur station is affected by interference, electrical noise is most often the culprit. Typical sources include power lines and consumer devices.

27.1.3 Personal Diplomacy

Whether the interference is to your station or from your station, what happens when you first talk to your neighbor sets the tone for all that follows. Any technical solutions cannot help if you are not allowed in your neighbor's house to explain them! If the interference is not caused by spurious emissions from your station, however, you should be a locator of solutions, not a provider of solutions.

Your neighbor will probably not understand all of the technical issues — at least not at first. Understand that, regardless of fault, interference is annoying whether your signals are causing interference to the neighbor or a device owned by the neighbor is causing interference to you.

Let your neighbor know that you want to help find a solution and that you want to begin by talking things over. Talk about some of the more important technical issues, in non-technical terms. Explain that you must also follow technical rules for your signal, such as for spurious emissions, and that you will check your station, as well.

27.1.4 Interference To a Neighbor's Equipment

Your transmitted signals can be the source of interference to a neighbor's equipment. Assure your neighbor that you will check your station thoroughly and correct any problems. You should also discuss the possible susceptibility of consumer equipment. You may want to print a copy of the RFI information found on the ARRL website at **www.arrl.org/information-for-the-neighbors-of-hams**. (This document, "What To Do if You Have an Electronic Interference Problem," is also included on the CD-ROM accompanying this book.)

Your neighbor will probably feel much better if you explain that you will help find a solution, even if the interference is not your fault. This offer can change your image from neighborhood villain to hero, especially if the interference is not caused by your station. (This is often the case.)

Here is a good analogy: If you tune your TV to channel 3, and see channel 8 instead, you would likely decide that your TV set is broken. Now, if you tune your TV to channel 3, and see your local shortwave radio station (quite possibly Amateur Radio), you shouldn't blame the shortwave station without some investigation. In fact, many televisions respond to strong signals outside the television bands. They may be working as designed, but require added filters and/or shields to work properly near a strong, local RF signal.

> **Warning: Performing Repairs**
>
> You are the best judge of a local situation, but the ARRL strongly recommends that you do not work on your neighbor's equipment. The minute you open up a piece of equipment, you may become liable for problems. Internal modifications to your neighbor's equipment may cure the interference problem, but if the equipment later develops some other problem, you may be blamed, rightly or wrongly. In some states, it is even *illegal* for you to do *any* work on electronic equipment other than your own.

27.1.5 Interference From a Neighbor's Equipment

Your neighbor is probably completely unaware that his or her equipment can interfere with your operation. You will have to explain that some home electronics equipment can generate radio signals many times stronger than the weak signals from a distant transmitter. Also explain that there are a number of ways to prevent those signals from being radiated and causing interference. If the equipment causing the problem can be identified, the owner's manual or manufacturer of the device may provide information on the potential for RFI and for its elimination.

As with interference appearing to be caused by your station, explain that your intent is to help find a solution. Without further investigation it is premature to assume that the neighbor's equipment is at fault or that FCC regulations require the neighbor to perform any corrective action. Working together to find a mutually acceptable solution is the best strategy.

27.1.6 Being Prepared

In order to troubleshoot and cure RFI, you need to learn more than just the basics. This is especially important when dealing with your neighbor. If you visit your neighbor's house and try a few dozen things that don't work (or make things worse), your neighbor may lose confidence in your ability to help cure the problem. If that happens, you may be asked to leave.

Start by carefully studying the technical sources and cures for RFI in this book and in other references, such as the *ARRL RFI Book*. Review some of the ARRL Technical Information Service and *QST* articles about interference. If you are unfamiliar with any of the terms in this chapter, refer to the glossary.

LOCAL HELP

If you are not an expert (and even experts can use moral support), you should find some local help. Fortunately, such help is often available from your ARRL Section's Technical Coordinator (TC). The TC knows of any local RFI committees and may have valuable contacts in the local utility companies. Even an expert can benefit from a TC's help. The easiest way to find your TC is through your ARRL Section Manager (SM). There is a list of SMs on the ARRL website or in any recent *QST*. He or she can quickly put you in contact with the best source of local help.

Even if you can't secure the help of a local expert, a second ham can be a valuable asset. Often a second party can help defuse any hostility. When evaluating and solving RFI problems involving your station, it is very im-

portant for two hams to be part of the process. One can operate your station and the other can observe symptoms, and, when appropriate, try solutions.

PREPARE YOUR HOME AND STATION

The first step toward curing the problem is to make sure your own signal is clean and that devices in your home are not causing any problems. Eliminate all interference issues in your own home to be sure your station is operating properly and that your own electronic equipment is not being interfered with or causing interference to your station!

This is also a valuable troubleshooting tool for situations in which your station is suspected of being the source of interference: If you know your signals are "clean," you have cut the size of the problem in half! If the FCC ever gets involved, you can demonstrate that you are not interfering with your own electronics.

Apply RFI cures to your own consumer electronics and computer equipment. What you learn by identifying and eliminating interference in your own home will make you better prepared to do so in your neighbor's home. When your neighbor sees your equipment working well, it also demonstrates that filters work and cause no harm.

To help build a better relationship, you may want to show your station to your neighbor. A well-organized and neatly-wired station inspires confidence in your ability to solve the RFI problem. Clean up your station and clean up the mess! A rat's nest of cables, unsoldered connections and so on can contribute to RFI. Grounding is typically not a cure for RFI, but proper grounding will improve lightning safety and can greatly reduce hum and buzz from power systems. Make sure cable shields are connected properly and that RF current picked up from your transmitted signal by audio and power wiring is minimized.

Install a low-pass or band-pass transmit filter. (In the unlikely event that the FCC becomes involved, they will ask you about filtering.) Show your neighbor that you have installed the necessary filter on your transmitter. Explain that if there is still interference, it is necessary to try filters on the neighbor's equipment, too.

Operating practices and station-design considerations can cause interference to TV and FM receivers. Don't overdrive a transmitter or amplifier; that can increase its harmonic output.

Along with applying some of the interference-reducing solutions in this chapter, you can also consider steps to reduce the strength of your signal at the victim equipment. This includes raising, moving, or re-orienting the antenna, or reducing transmit power. The use of a balun and properly balanced feed line will minimize radiation from your station feed line. (See the **Transmission Lines** chapter.) Changing antenna polarization may help, such as if a horizontal dipole is coupling to a cable TV service drop. Using different modes, such as CW or FM, may also change the effects of the interference. Although the goal should be for you to operate as you wish with no interference, be flexible in applying possible solutions.

27.1.7 Contacting Your Neighbor

Now that you have learned more about RFI, located some local help (we'll assume it's the TC) and done all of your homework, make contact with your neighbor. First, arrange an appointment convenient for you, the TC and your neighbor. After you introduce the TC, allow him or her to explain the issues to your neighbor. Your TC will be able to answer most questions, but be prepared to assist with support and additional information as required.

Invite the neighbor to visit your station. Show your neighbor some of the things you do with your radio equipment. Point out any test equipment you use to keep your station in good working order. Of course, you want to show the filter you have installed on your transmitter's output.

Next, have the TC operate your station on several different bands while you show your neighbor that your home electronics equipment is working properly when your station is transmitting. Point out the filters or chokes you have installed to correct any RF susceptibility problems. If the interference is coming from the neighbor's home, show it to the neighbor and explain why it is a problem for you.

At this point, tell your neighbor that the next step is to try some of the cures seen in your home and station on his or her equipment. This is a good time to emphasize that the problem is probably not your fault, but that you and the TC will try to help find a solution anyway.

Study the section on Troubleshooting RFI before deciding what materials and techniques are likely to be required. You and the TC should now visit the neighbor's home and inspect the equipment installation.

AT YOUR NEIGHBOR'S HOME

Begin by asking when the interference occurs, what equipment is involved, and what frequencies or channels are affected, if appropriate. The answers are valuable clues. Next, the TC should operate your station while you observe the effects. Try all bands and modes that you use. Ask the neighbor to demonstrate the problem. Seeing your neighbor's interference firsthand will help all parties feel more comfortable with the outcome of the investigation.

If it appears that your station is involved, note all conditions that produce interference. If no transmissions produce the problem, your station *may* not be the source. (It's possible that some contributing factor may have been missing in the test.) Have your neighbor keep notes of when and how the interference appears: what time of day, what channels or device was being interfered with, what other equipment was in use, what was the weather? You should do the same whenever you operate. If you can readily reproduce the problem, you can start to troubleshoot the problem. This process can yield important clues about the nature of the problem.

The tests may show that your station isn't involved at all. A variety of equipment malfunctions or external noise can look like interference. Some other nearby transmitter or noise source may be causing the problem. You may recognize electrical noise or some kind of equipment malfunction. If so, explain your findings to the neighbor and suggest that he or she contact appropriate service personnel.

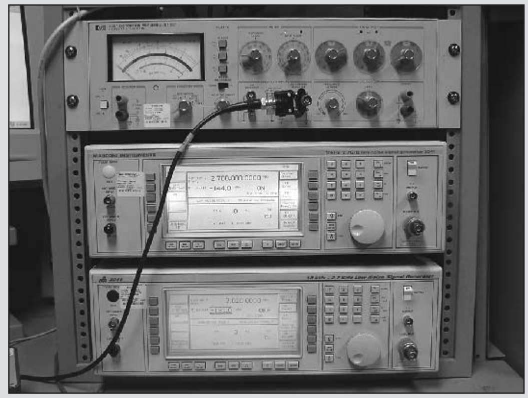
If the interference is to your station from equipment that may be in the neighbor's home, begin by attempting to identify which piece of equipment is causing the problem. Describe when you are receiving the interference and what pattern it seems to have (continuous, pulsed, intermittent, certain times of day, and so on).

Confirm that a specific piece of equipment is causing the problem. The easiest way to do this is to physically unplug the power source or by removing the batteries while you or the TC observe at your station. (Remember that turning a piece of equipment OFF with its ON/OFF switch may not cause the equipment to completely power down.) Removing cables from a powered-up piece of equipment may serve to further isolate the problem.

At this point, the action you take will depend on the nature of the problem and its source. Techniques for dealing with specific interference issues are discussed in the following sections of the chapter. If you are unable to determine the exact nature of the problem, develop a plan for continuing to work with the neighbor and continue to collect information about the behavior of the interference.

Product Review Testing and RFI

The ARRL Laboratory mostly considers RFI as an outside source interfering with the desired operation of radio reception. Power line noise, power supplies, motor controls and light dimmers are all *outside* a radio receiver and antenna system and can be a major annoyance that distracts from the pleasure of operating. Have you ever considered RFI generated *inside* your own receiver or by another legally operating Amateur Radio station?



The Lab uses these signal generators to test receivers for internally generated intermodulation distortion, as well as other key performance parameters.

Harmonics

RFI is just that: radio frequency interference. For instance, a harmonic from another radio amateur's transmitter could be interfering with the desired signal you're tuned to. One might think in this day and age, harmonics are minimal and do not cause interference. I ask you to reconsider.

The maximum spurious output of a modern amateur transmitter must be 43 dB lower than the output on the carrier frequency at frequencies below 30 MHz. While that figure may be "good enough" for an FCC standard, it's not good enough to eliminate the possibility of causing interference to other radio amateurs or possibly other services. Here at the ARRL Laboratory, the measurement of harmonic emission level is a measurement I make of RFI generated *outside* your receiver.

A radio amateur contacted me, concerned about a report that he was causing interference to operators on the 80 meter CW band while operating at full legal limit power during a 160 meter CW contest. Knowing FCC rule part 97.307, he made the effort to measure his 80 meter harmonic. Easily meeting FCC standards at 50 dB below carrier output on 160, he wondered how his transmitter could cause interference.

Here's a breakdown of power output and signal reduction:

0 dB down from 1500 W = 1500 W
10 dB down from 1500 W = 150 W
20 dB down from 1500 W = 15 W
30 dB down from 1500 W = 1.5 W
40 dB down from 1500 W = 150 mW
43 dB down from 1500 W = 75.2 mW (this is the FCC legal limit)
50 dB down from 1500 W = 15 mW

While 15 mW may seem too low of a power to cause interference, it wasn't in this case; the interfering signal was reported to be S9. QRP enthusiasts know that at 15 mW, signals can propagate well with the right conditions. Using a single band, resonant antenna will reduce interference caused by harmonics located on other bands, but today many stations employ antennas resonant on more than one ham band.[1]

Signals Generated in the Receiver

What about RFI generated *inside* the receiver you're operating? You're tuning across the 15 meter band when, all of a sudden, you hear what seems to be an AM broadcast station. Is it a jammer? It is definitely interference — radio frequency interference — caused by two strong shortwave stations! In this particular case, a Midwest radio amateur experienced interference on 15 meters and figured out what was happening. One station was transmitting near 6 MHz and another transmitting above 15 MHz. These two strong stations added up to created a second order IMD (intermodulation distortion) product at the 1st IF stage, and this unwanted signal was passed along to subsequent stages and to the speaker. The RFI in this case was caused by insufficient receiver performance (second order IMD dynamic range) where the frequencies of the two stations added up to exactly the frequency that the operator was tuned to. Third-order IMD products from strong in-band signals are another form of RFI created within a radio receiver.

Nearby stations transmitting at or near the IF frequency will cause interference not because the transmitter is at fault, but because of a receiver's insufficient IF rejection. The same interference will be heard if a nearby transmitter is operating at an image frequency.

Power Supplies

RFI can also be created from another part of a radio system, such as an external power supply. In addition to transmitter and receiver testing, the Lab also measures the conducted emission levels of power supplies. This is an indication of the amount of RF at given frequencies conducted onto power lines from a power supply as described in this chapter.

Through our published Product Review test results in *QST* magazine, readers can compare the above figures of modern HF transceivers when considering the purchase of a new or used transceiver. Our published data tables spawn friendly competition between radio manufacturers who in turn, strive to perfect their circuit designs. The result is a better product for the manufacturer and a better product for you, the radio amateur. — *Bob Allison, WB1GCM, ARRL Test Engineer*

The ARRL Lab maintains a complete set of up-to-date equipment as well as an RF-tight screen room for Product Review testing. [Bob Allison, WB1GCM, photo]

[1]In this case, the use of a bandpass filter designed for 160 meters would significantly attenuate the harmonic on 80 meters, eliminating the interference.

27.2 FCC Rules and Regulations

In the United States most unlicensed electrical and electronic devices are regulated by Part 15 of the FCC's rules. These are referred to as "Part 15 devices." Most RFI issues reported to the ARRL involve a Part 15 device. Some consumer equipment, such as certain wireless and lighting devices, is covered under FCC Part 18 which pertains to ISM (Industrial, Scientific and Medical) devices.

The Amateur service is regulated by FCC Part 97. (Part 97 rules are available online at **www.arrl.org/part-97-amateur-radio.** See also the sidebar "RFI-related FCC Rules and Definitions.") To be legal, the amateur station's signal must meet all Part 97 technical requirements, such as for spectral purity and power output.

As a result, it isn't surprising that most interference complaints involve multiple parts of the FCC rules. (The FCC's jurisdiction does have limits, though — ending below 9 kHz.) It is also important to note that each of the three parts (15, 18 and 97) specifies different requirements with respect to interference, including absolute emissions limits and spectral purity requirements. The FCC does not specify *any* RFI immunity requirements. Most consumer devices therefore receive no FCC protection from a legally licensed transmitter, including an amateur transmitter operating legally according to Part 97.

Licensed services are protected from interference to their signals, even if the interference is generated by another licensed service transmitter. For example, consider TVI from an amateur transmitter's spurious emissions, such as harmonics, that meet the requirements of Part 97 but are still strong enough to be received by nearby TV receivers. The TV receiver itself is not protected from interference under the FCC rules. However, within its service area the licensed TV broadcast signal is protected from harmful interference caused by spurious emissions from other licensed transmitters. In this case, the amateur transmitter's interfering spurious emission would have to be eliminated or reduced to a level at which harmful interference has been eliminated.

27.2.1 FCC Part 97 Rules

While most interference to consumer devices may be caused by a problem associated with the consumer device as opposed to the signal source, all amateurs must still comply with Part 97 rules. Regardless of who is at fault, strict conformance to FCC requirements, coupled with a neat and orderly station appearance, will go far toward creating a good and positive impression in the event of an FCC field investigation. Make sure your station and signal exhibit good engineering and operating practices.

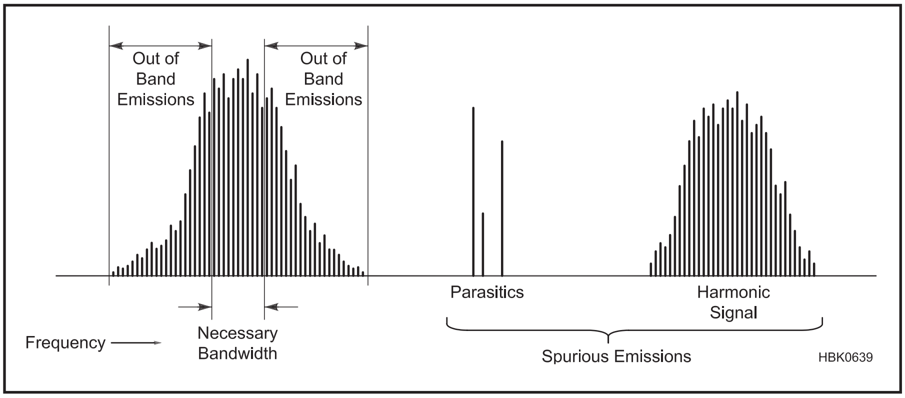


Fig 27.1 — An illustration of out-of-band versus spurious emissions. Some of the modulation sidebands are outside the necessary bandwidth. These are considered out-of-band emissions, not spurious emissions. The harmonic and parasitic emissions shown here are considered spurious emissions; these must be reduced to comply with §97.307.

What If the Police Are Called?

Many amateurs have had a similar experience. You are enjoying some time in front of the radio when the doorbell rings. When you answer the door, you find an irate neighbor has called the police about your transmissions interfering with their stereo (or cordless telephone or other home electronics). The officer tells you that you are interfering with your neighbor and orders you to stop transmissions immediately.

The bad news is you are in the middle of a bad situation. The good news is that most cases of interference can be cured! The proper use of "diplomacy" skills to communicate with a neighbor and standard technical cures will usually solve the problem. Even more good news is that if you are operating in accordance with your license and employing good engineering practices, the law and FCC rules are on your side.

Most RFI is caused by the unfortunate fact that most consumer equipment lacks the necessary filtering and shielding to allow it to work well near a radio transmitter. The FCC does not regulate the immunity of equipment, however, so when interference is caused by consumer-equipment fundamental overload, there is no FCC rules violation, and licensed stations have no regulatory responsibility to correct interference that may result.

Further, in 1982, Congress passed Public Law 97-259. This law is specific and reserves exclusive jurisdiction over RFI matters to the Federal Communications Commission. This national law preempts any state or local regulations or ordinances that attempt to regulate or resolve RFI matter. This is a victory for amateurs (and other services operating with the legal and technical provisions of their licenses).

Simply put, 97-259 says that cities and towns may not pass ordinances or regulations that would prohibit someone from making legal radio transmissions. But what do you do when your neighbor (or the police) confront you about RFI to their consumer electronics? First and foremost, remain calm. In all likelihood the officer or your neighbor has probably never heard of 97-259. Don't get defensive and get drawn into an argument. Don't make comments that the problem is with the neighbor's "cheap" equipment. While inexpensive radios are usually big culprits, any home electronics are potential problems due to inadequate technical designs.

Begin by listening to the complaint. Explain that while you understand, you are operating your equipment within its technical specifications. If your equipment doesn't interfere with your own home electronics, offer to demonstrate that to the officer. Also explain the basics of PL 97-259. If the officer (or neighbor) continues to insist that regardless of the law that you cease, consider temporarily complying with his or her request, with the understanding that you are doing so until the matter is resolved.

Work with your neighbors to understand that steps can be taken that should help resolve the problems (for example, placing toroids and filters on the consumer electronics). The ARRL website has lots of helpful information as you work to resolve the problems. If your club has a local RFI committee or ARRL Technical Specialist, get them involved — their expertise can really be helpful. But above all, remember that when you practice easy, level-headed "diplomacy" you can usually keep the situation from escalating. — *Dan Henderson, N1ND, ARRL Regulatory Information Manager*

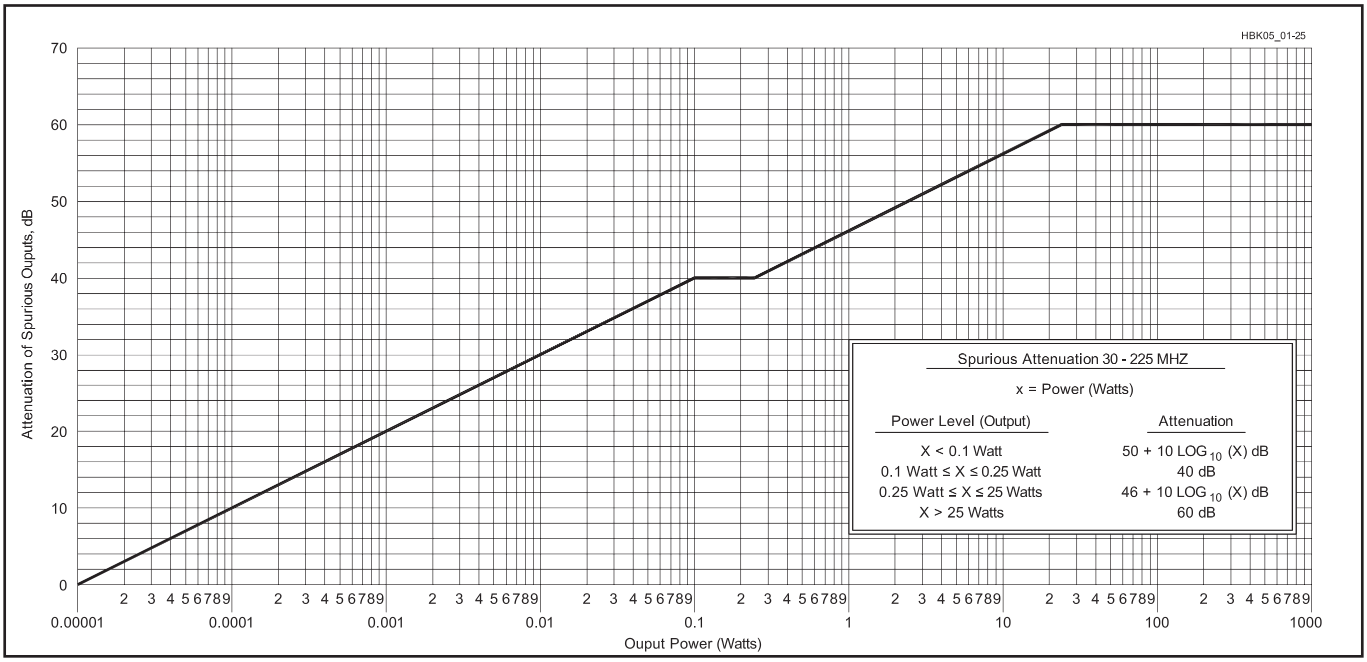


Fig 27.2 — Required attenuation of spurious outputs, 30-225 MHz. Below 30 MHz, spurious emissions must be suppressed by 43 dB for amateur transmitters installed after January 1, 2003.

The bandwidth of a signal is defined by §97.3(a)(8) while the paragraphs of §97.307 define the technical standards amateur transmissions must meet. Paragraph (c) defines the rules for interference caused by spurious emissions. As illustrated in **Fig 27.1**, modulation sidebands outside the necessary bandwidth are considered *out-of-band* emissions, while harmonics and parasitic signals are considered *spurious emissions*. Paragraphs (d) and (e) specify absolute limits on spurious emissions, illustrated in **Fig 27.2**. Spurious emissions must not exceed these levels, whether or not the emissions are causing interference. If spurious emissions from your transmitter are causing interference, it's your responsibility to clean them up.

Strict observance of these rules can not only help minimize interference to the amateur service, but other radio services and consumer devices as well.

27.2.2 FCC Part 15 Rules

In the United States, most unlicensed devices are regulated by Part 15 of the FCC's rules. While understanding these rules doesn't necessarily solve an RFI problem, they do provide some important insight and background on interference to and from a Part 15 device. (Part 18 devices and rules are similar in some respects) and will not be discussed separately — see the sidebar.)

There are literally thousands of Part 15 devices with the potential to be at the heart of an RFI problem. A Part 15 device can be almost anything not already covered in another

FCC Part 18, Consumer Devices

Some consumer devices are regulated by Part 18 of the FCC Rules which pertains to the Industrial, Scientific and Medical (ISM) bands. These devices convert RF energy directly into some other form of energy, such as heat, light or ultrasonic sound energy. Some common household Part 18 devices therefore include microwave ovens, electronic fluorescent light ballasts, CFLs, and ultrasonic jewelry cleaners. (Note that LED bulbs are covered under Part 15 because of the process by which they generate light.)

Consumer Part 18 devices are generators of RF — but not for communications purposes — and can cause interference in some cases. However, there are no rules that protect them from interference. The purpose of Part 18 is to permit those devices to operate and to establish rules prohibiting interference.

From the standpoint of an RFI problem, Part 18 rules aren't much different from Part 15. As with a Part 15 device, a Part 18 device is required to meet specified emissions limits. Furthermore, it must not cause harmful interference to a licensed radio service.

Part 18 Rules and the 33 cm Band

Part 18 specifies a number of bands for ISM (industrial, scientific, and medical) devices. The so-called ISM bands in some cases overlap amateur spectrum. For example, the entire 33 cm band from 902 to 928 MHz is both an amateur and ISM band. And, as the following rule from Part 97 indicates, the amateur service is not protected from ISM devices operating in this or any other ISM band:

§ 97.303 (e) Amateur stations receiving in the 33 cm band, *the 2400-2450 MHz segment, the 5.725-5.875 GHz segment, the 1.2 cm band, the 2.5 mm band, or the 244-246 GHz segment must accept interference from industrial, scientific, and medical (ISM) equipment.*

Additional restrictions apply in some areas of the country when using the 33 cm band.

- Amateurs located in some parts of Colorado and Wyoming may not transmit in some parts of this band.
- Amateurs located in some parts of Texas and New Mexico are prohibited from using this band.
- Amateurs located within 150 miles of White Sands Missile Range are limited to 150 W PEP.

Amateurs in these areas are responsible for knowing the boundaries of these areas and observing all applicable rules. See the latest edition of the *ARRL Repeater Directory* for more information and boundary details.

RFI-related FCC Rules and Definitions

Here are some of the most important rules and definitions pertaining to RFI and the Amateur Radio Service. Definitions in Part 2 are used in regulations that apply to all radio services.

§2.1 Definitions

Harmful Interference. Interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with [the ITU] Radio Regulations.

Interference. The effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radiocommunication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy.

Out-of-band Emission. Emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emissions. Band does not mean "amateur band" here.

§97.3 Definitions

(a) The definitions of terms used in Part 97 are:

(8) Bandwidth. The width of a frequency band outside of which the mean power of the transmitted signal is attenuated at least 26 dB below the mean power of the transmitted signal within the band.

(23) Harmful interference. (see the previous Part 2 definition)

(42) Spurious emission. An emission, on frequencies outside the necessary bandwidth of a transmission, the level of which may be reduced without affecting the information being transmitted.

§97.307 Emission standards

(a) No amateur station transmission shall occupy more bandwidth than necessary for the information rate and emission type being transmitted, in accordance with good amateur practice.

(b) Emissions resulting from modulation must be confined to the band or segment available to the control operator. Emissions outside the necessary bandwidth must not cause splatter or key-click interference to operations on adjacent frequencies.

(c) All spurious emissions from a station transmitter must be reduced to the greatest extent practicable. If any spurious emission, including chassis or power line radiation, causes harmful interference to the reception of another radio station, the licensee of the interfering amateur station is required to take steps to eliminate the interference, in accordance with good engineering practice.

(d) For transmitters installed after January 1, 2003, the mean power of any spurious emission from a station transmitter or external RF amplifier transmitting on a frequency below 30 MHz must be at least 43 dB below the mean power of the fundamental emission. For transmitters installed on or before January 1, 2003, the mean power of any spurious emission from a station transmitter or external RF power amplifier transmitting on a frequency below 30 MHz must not exceed 50 mW and must be at least 40 dB below the mean power of the fundamental emission. For a transmitter of mean power less than 5 W installed on or before January 1, 2003, the attenuation must be at least 30 dB. A transmitter built before April 15, 1977, or first marketed before January 1, 1978, is exempt from this requirement.

(e) The mean power of any spurious emission from a station transmitter or external RF power amplifier transmitting on a frequency between 30-225 MHz must be at least 60 dB below the mean power of the fundamental. For a transmitter having a mean power of 25 W or less, the mean power of any spurious emission supplied to the antenna transmission line must not exceed 25 µW and must be at least 40 dB below the mean power of the fundamental emission, but need not be reduced below the power of 10 µW. A transmitter built before April 15, 1977, or first marketed before January 1, 1978, is exempt from this requirement.

Part of the FCC rules. In fact, many Part 15 devices may not normally even be associated with electronics, RF or in some cases, electricity. While televisions, radios, telephones and even computers obviously constitute a Part 15 device, the rules extend to anything that is capable of generating RF, including electric motors and consumer devices such as baby monitors, wireless microphones and intercoms, RF remote controls, garage door openers, etc. With so many Part 15 consumer devices capable of generating and responding to RF, it isn't surprising therefore that most reported RFI problems involving Amateur Radio also involve a Part 15 device.

TYPES OF PART 15 DEVICES

Part 15 describes three different types of devices that typically might be associated with an RFI problem. A fourth type of device, called a *carrier current device*, uses power lines and wiring for communications purposes. As we'll see, the rules are different for each type.

Intentional Emitters — Intentionally generate RF energy and radiate it. Examples include garage door openers, cordless phones and baby monitors.

Unintentional Emitters — Intentionally generate RF energy internally, but do not intentionally radiate it. Examples include computers and network equipment, superheterodyne receivers, switchmode power supplies and TV receivers.

Incidental Emitters — Generate RF energy only as an incidental part of their normal operation. Examples include power lines, arcing electric fence, arcing switch contacts, dc motors and mechanical light switches.

Carrier Current Devices — Intentionally generate RF and conduct it on power lines and/or house wiring for communications purposes. Examples include Powerline and X.10 networks, Access or In-House Broadband-Over-Power-Line (BPL), campus radio-broadcast systems, and other power-line communications devices.

PART 15 SUMMARY

FCC's Part 15 rules pertain to unlicensed devices and cover a lot of territory. Although reading and understanding Part 15 can appear rather formidable — especially at first glance — the rules pertaining to RFI can be roughly summarized as follows:

- Part 15 devices operate under an unconditional requirement to not cause harmful interference to a licensed radio service, such as Amateur Radio. If such interference occurs, the operator of the Part 15 device is responsible for eliminating the interference.
- Part 15 devices receive no protection from interference from a licensed radio service. There are no FCC rules or limits with regard to Part 15 device RFI immunity.

When is the operator of a licensed transmitter responsible for interference to a Part 15 device?

- The rules hold the transmitter operator responsible if interference is caused by spurious emissions such as a harmonic. An example would be a harmonic from an amateur's transmitter interfering with a cordless telephone. In this case, the transmitter is generating harmful RF energy beyond its permitted bandwidth. A cure must be installed at the transmitter.
- The transmitter operator is not responsible when a Part 15 device is improperly responding to a legal and intentional output of the transmitter. An example of this case would be interference to a cordless telephone

operation by the strong-but-legal signal from a nearby amateur transmitter. In this case, the Part 15 device is at fault and the cure must be installed there. It is important to note that this situation is typical of most interference to Part 15 devices.

Even though the causes and cures for these situations are different, the common element for all three situations is the need for personal diplomacy in resolving the problem.

PART 15 MANUFACTURER REQUIREMENTS

Under FCC rules, both device manufactures and operators of those devices share responsibility for addressing an RFI problem. The rules for manufacturers are primarily designed to reduce the possibility of harmful interference. They do not however completely eliminate the possibility of an RFI problem. If and when interference does occur, the rules are designed to minimize and confine the scope of problems such that they can be addressed on a case by case basis. Responsibility

Part 15 Absolute Emissions Limits for Unintentional Emitters

§15.107 Conducted limits

(a) Except for Class A digital devices, for equipment that is designed to be connected to the public utility (ac) power line, the radio frequency voltage that is conducted back onto the ac power line on any frequency or frequencies within the band 150 kHz to 30 MHz shall not exceed the limits in the following table, as measured using a 50 µH/50 ohms line impedance stabilization network (LISN). Compliance with the provisions of this paragraph shall be based on the measurement of the radio frequency voltage between each power line and ground at the power terminal. The lower limit applies at the band edges.

Conducted Limits — Non Class-A Digital Devices

Frequency of emission (MHz)	*Conducted limit (dBµV) Quasi-peak*	*Average*
0.15–0.5	66 to 56*	56 to 46*
0.5–5	56	46
5–30	60	50

*Decreases with the logarithm of the frequency.

(b) For a Class A digital device that is designed to be connected to the public utility (ac) power line, the radio frequency voltage that is conducted back onto the ac power line on any frequency or frequencies within the band 150 kHz to 30 MHz shall not exceed the limits in the following table, as measured using a 50 µH/50 ohms LISN. Compliance with the provisions of this paragraph shall be based on the measurement of the radio frequency voltage between each power line and ground at the power terminal. The lower limit applies at the boundary between the frequency ranges.

Conducted Limits — Class-A Digital Devices

Frequency of emission (MHz)	*Conducted limit (dBµV) Quasi-peak*	*Average*
0.15–0.5	79	66
0.5–30	73	60

(c) The limits shown in paragraphs (a) and (b) of this section shall not apply to carrier current systems operating as unintentional radiators on frequencies below 30 MHz. In lieu thereof, these carrier current systems shall be subject to the following standards:

(1) For carrier current systems containing their fundamental emission within the frequency band 535-1705 kHz and intended to be received using a standard AM broadcast receiver: no limit on conducted emissions.

(2) For all other carrier current systems: 1000 µV within the frequency band 535–1705 kHz, as measured using a 50 µH/50 ohms LISN.

(3) Carrier current systems operating below 30 MHz are also subject to the radiated emission limits in §15.109(e).

(d) Measurements to demonstrate compliance with the conducted limits are not required for devices which only employ battery power for operation and which do not operate from the ac power lines or contain provisions for operation while connected to the ac power lines. Devices that include, or make provision for, the use of battery chargers which permit operating while charging, ac adaptors or battery eliminators or that connect to the ac power lines indirectly, obtaining their power through another device which is connected to the ac power lines, shall be tested to demonstrate compliance with the conducted limits.

§ 15.109 Radiated emission limits

(a) Except for Class A digital devices, the field strength of radiated emissions from unintentional radiators at a distance of 3 meters shall not exceed the following values:

Radiated Limits — Non Class-A Digital Devices

Frequency of emission (MHz)	*Field Strength (µV/meter)*
30–88	100
88–216	150
216–960	200
Above 960	500

(b) The field strength of radiated emissions from a Class A digital device, as determined at a distance of 10 meters, shall not exceed the following:

Radiated Limits — Class-A Digital Devices

Frequency of emission (MHz)	*Field Strength (µV/meter)*
30–88	90
88–216	150
216–960	210
Above 960	300

(c) In the emission tables above, the tighter limit applies at the band edges. Sections 15.33 and 15.35 which specify the frequency range over which radiated emissions are to be measured and the detector functions and other measurement standards apply.

(d) For CB receivers, the field strength of radiated emissions within the frequency range of 25–30 MHz shall not exceed 40 microvolts/meter at a distance of 3 meters. The field strength of radiated emissions above 30 MHz from such devices shall comply with the limits in paragraph (a) of this section.

(e) Carrier current systems used as unintentional radiators or other unintentional radiators that are designed to conduct their radio frequency emissions via connecting wires or cables and that operate in the frequency range of 9 kHz to 30 MHz, including devices that deliver the radio frequency energy to transducers, such as ultrasonic devices not covered under part 18 of this chapter, shall comply with the radiated emission limits for intentional radiators provided in §15.209 for the frequency range of 9 kHz to 30 MHz. As an alternative, carrier current systems used as unintentional radiators and operating in the frequency range of 525 kHz to 1705 kHz may comply with the radiated emission limits provided in §15.221(a). At frequencies above 30 MHz, the limits in paragraph (a), (b), or (g) of this section, as appropriate, apply.

RFI-related Part 15 FCC Rules and Definitions

The FCC's Part 15 rules are found in Title 47 section of the Code of Federal Regulations (CFR). They pertain to unlicensed devices. Here are some of the more important Part 15 rules and definitions pertaining to RFI.

§15.3 Definitions.

(m) ***Harmful interference.*** Any emission, radiation or induction that endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs or repeatedly interrupts a radio communications service operating in accordance with this chapter.

(n) ***Incidental radiator.*** A device that generates radio frequency energy during the course of its operation although the device is not intentionally designed to generate or emit radio frequency energy.

(o) ***Intentional radiator***. A device that intentionally generates and emits radio frequency energy by radiation or induction.

(z) ***Unintentional radiator.*** A device that intentionally generates radio frequency energy for use within the device, or that sends radio frequency signals by conduction to associated equipment via connecting wiring, but which is not intended to emit RF energy by radiation or induction.

(t) ***Power line carrier systems.*** An unintentional radiator employed as a carrier current system used by an electric power utility entity on transmission lines for protective relaying, telemetry, etc. for general supervision of the power system. The system operates by the transmission of radio frequency energy by conduction over the electric power transmission lines of the system. The system does not include those electric lines which connect the distribution substation to the customer or house wiring.

(ff) ***Access Broadband over Power Line (Access BPL).*** A carrier current system installed and operated on an electric utility service as an unintentional radiator that sends radio frequency energy on frequencies between 1.705 MHz and 80 MHz over medium voltage lines or over low voltage lines to provide broadband communications and is located on the supply side of the utility service's points of interconnection with customer premises. Access BPL does not include power line carrier systems as defined in §15.3(t) or In-House BPL as defined in §15.3(gg).

(gg) ***In-House Broadband over Power Line (In-House BPL)***. A carrier current system, operating as an unintentional radiator, that sends radio frequency energy by conduction over electric power lines that are not owned, operated or controlled by an electric service provider. The electric power lines may be aerial (overhead), underground, or inside the walls, floors or ceilings of user premises. In-House BPL devices may establish closed networks within a user's premises or provide connections to Access BPL networks, or both.

Some of the most important Part 15 rules pertaining to radio and television interference from unintentional and incidental radiators include:

§15.5 General conditions of operation.

(b) Operation of an intentional, unintentional, or incidental radiator is subject to the conditions that no harmful interference is caused and that interference must be accepted that may be caused by the operation of an authorized radio station, by another intentional or unintentional radiator, by industrial, scientific and medical (ISM) equipment, or by an incidental radiator.

(c) The operator of the radio frequency device shall be required to cease operating the device upon notification by a Commission representative that the device is causing harmful interference. Operation shall not resume until the condition causing the harmful interference has been corrected.

§15.13 Incidental radiators.

Manufacturers of these devices shall employ good engineering practices to minimize the risk of harmful interference.

§15.15 General technical requirements.

(c) Parties responsible for equipment compliance should note that the limits specified in this part will not prevent harmful interference under all circumstances. Since the operators of Part 15 devices are required to cease operation should harmful interference occur to authorized users of the radio frequency spectrum, the parties responsible for equipment compliance are encouraged to employ the minimum field strength necessary for communications, to provide greater attenuation of unwanted emissions than required by these regulations, and to advise the user as to how to resolve harmful interference problems (for example, see Sec. 15.105(b)).

§15.19 Labeling requirements.

(a) In addition to the requirements in part 2 of this chapter, a device subject to certification, notification, or verification shall be labeled as follows:

(3) All other devices shall bear the following statement in a conspicuous location on the device:

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

And the following requirements apply for consumer and residential Class B digital devices. Different requirements apply for Class A digital devices which can only be used in industrial and similar environments:

§15.105 Information to the user.

(b) For a Class B digital device or peripheral, the instructions furnished the user shall include the following or similar statement, placed in a prominent location in the text of the manual:

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

Reorient or relocate the receiving antenna.

Increase the separation between the equipment and receiver.

Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.

Consult the dealer or an experienced radio/TV technician for help.

then falls on the device operator to correct the problem or cease using the device.

Manufacturers are subject to requirements that they use good engineering practice to help minimize the potential for interference. In addition, they must meet certain absolute conducted and radiated emissions limits for intentional and unintentional emitters. (See the sidebar for limits on conducted and radiated emissions.) These limits are high enough that S9+ interference levels can occur nearby, depending on frequency, distance and other factors. In fact, most reported Part 15 consumer products causing harmful interference to Amateur Radio are legal and meet these required limits. Therefore, the fact that a particular device is causing harmful interference is not in itself evidence or proof of a rules violation with regard to emissions limits.

With the exception of intentional emitters and carrier-current devices, there are no absolute radiated emissions limits below 30 MHz. The size of a Part 15 device is usually small relative to the wavelength at these frequencies. It is typically too small to be an effective antenna at these longer wavelengths. Therefore, under the FCC rules, only conducted emissions are specified below 30 MHz. (Note that cables and wiring connected to the devices are often effective at radiating signals and are frequent sources of radiated RFI.)

In general, radiated emissions limits are specified only at frequencies above 30 MHz. At the shorter wavelengths above 30 MHz, the device itself is large enough to be a radiator. Wiring connected to it can also be an effective antenna for radiating noise.

Although incidental radiators do not have any absolute emissions limits, as for all Part 15 devices, manufacturers must still employ good engineering practice to minimize the potential for interference.

The FCC also requires manufacturers to add information as a label to most Part 15 devices or as text in the device's operating manual. This information attests to the potential for interference and to the responsibility of the device operator. It must be placed in a conspicuous location on the device or in the manual and contain the following statement:

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Owners of Part 15 devices are frequently unaware of this information and surprised to find it on the device or in its manual. Reading this label can be an important step in resolving RFI issues. Additional details regarding labeling requirements can be found in the sidebar on Part 15 Rules.

EQUIPMENT AUTHORIZATION

FCC regulations do not require Part 15 devices to be tested by the FCC. In fact, very few devices must actually undergo FCC testing. In most cases, the requirements are met by the manufacturer testing the device and the test results either kept on file or sent to the FCC, depending on the type of device involved. Here is some general information concerning various FCC approval processes for RF devices:

- *Certification:* Requires submittal of an application that includes a complete technical description of the product and a measurement report showing compliance with the FCC technical standards. Certification procedures have now largely replaced the once familiar Type Acceptance, which is no longer used by the FCC. Devices subject to certification include: low-power transmitters such as cordless telephones, security alarm systems, scanning receivers, super-regenerative receivers, Amateur Radio external HF amplifiers and amplifier kits, and TV interface devices such as DVD players.
- *Declaration of Conformity (DoC)*: Is a declaration that the equipment complies with FCC requirements. A DoC is an alternative to certification since no application to FCC is required, but the applicant must have the device tested at an accredited laboratory. A Declaration of Conformity is the usual approval procedure for Class B personal computers and personal computer peripherals.
- *Notification*: Requires submittal to the FCC of an abbreviated application for equipment authorization which does not include a measurement report. However, a measurement report showing compliance of the product with the FCC technical standards must be retained by the applicant and must be submit-

RF Interference and the FCC

by Riley Hollingsworth, K4ZDH

Since 1999, the FCC has worked with the ARRL in a cooperative agreement whereby the staff at the ARRL Lab takes the first cut at resolving RFI. The lab works with the complainant to make sure that the noise is narrowed down to the most probable source. The success rate with this program has been very high, and in many cases — perhaps most — the ARRL and the complainant solve the problem without any FCC involvement.

The lab can help you with the proper testing you need to do in your shack and with the documentation you need in the event the matter is referred to the FCC. Just hearing the noise will often tip off the ARRL staff as to its source. I was always amazed at the number of situations in which noise that at first seemed to be power line related, was in fact (these are real examples) a nearby electric fence, a battery charger for a golf cart, an Ethernet adapter, a paper shredder or a circuit board in a brand new clothes washer in a room adjacent to the radio shack.

Don't assume anything. Test every possibility and document your testing. Not only will you learn a lot about the devices in your house and what causes noise and what doesn't, but good documentation will make your case stronger and easier to work. Follow to the letter the ARRL articles and website tutorials on tracking down noise in and around your shack. You can even hear noise samples on the website.

The documentation requirement is especially important if it is power line related and you have to start dealing with the power company. Take notes of every call you make, who you talked to and when. This helps not only the power company but also the FCC in the unfortunate event that FCC action is required. In many cases, power company staff has a lot of experience running down such noise and they take pride in locating it. In other cases, the power company has been bought, sold, merged or whatever and does not have staff with a lot of experience in these matters. Sometimes its staff has no experience.

The cost of the equipment required to track down power line noise is less than that of two employees and a bucket truck for a day. Often the source of power line noise is a simple piece of equipment that is loose or about to fail, so finding the source helps the power company maintain its system. Keep in mind, though, that some areas are just not suitable for Amateur Radio. If you live next to an old substation, or a conglomeration of old poles and transformers, or an industrial area, your situation is tenuous. Whether it's our roads or power grids, lots of the infrastructure in this country is just plain old and out of date.

You must test diligently and document thoroughly. Never go to the FCC with a situation when you have not already worked with the ARRL and the power company.

ted upon request by the Commission. Devices subject to notification include: point-to-point microwave transmitters, AM, FM and TV broadcast transmitters and other receivers (except as noted elsewhere).

• *Verification*: Verification is a self-approval process where the applicant performs the necessary tests and verifies that they have been done on the device to be authorized and that the device is in compliance with the technical standards. Verified equipment requires that a compliance label be affixed to the device as well as information included in the operating manual regarding the interference potential of the device. Devices subject to verification include: business computer equipment (Class A); TV and FM receivers; and non-consumer Industrial, Scientific and Medical Equipment.

PART 15 OPERATOR REQUIREMENTS

All Part 15 devices are prohibited from causing harmful interference to a licensed radio service — including the Amateur Radio Service. This is an absolute requirement without regard to the emitter type or a manufacturer's conformance to emissions limits or other FCC technical standards. It is important to note that the manufacturer's requirements are not sufficient to prevent harmful interference from occurring under all circumstances. If and when a Part 15 device generates harmful interference, it becomes the responsibility of the device operator to correct the problem. Upon notice from the FCC, the device operator may also be required to cease using the device until such time as the interference has been corrected.

27.3 Elements of RFI

27.3.1 Source-Path-Victim

All cases of RFI involve a *source* of radio frequency energy, a device that responds to the electromagnetic energy (*victim*), and a transmission *path* that allows energy to flow from the source to the victim. Sources include radio transmitters, receiver local oscillators, computing devices, electrical noise, lightning and other natural sources. Note that receiving unwanted electromagnetic energy does not necessarily cause the victim to function improperly.

A device is said to be *immune* to a specific source if it functions properly in the presence of electromagnetic energy from the source. In fact, designing devices for various levels of immunity is one aspect of electromagnetic compatibility engineering. Only when the victim experiences a *disturbance* in its function as a consequence of the received electromagnetic energy does RFI exist. In this case, the victim device is *susceptible* to RFI from that source.

There are several ways that RFI can travel from the source to the victim: *radiation*, *conduction*, *inductive coupling* and *capacitive coupling*. *Radiated RFI* propagates by electromagnetic radiation from the source through space to the victim. *Conducted RFI* travels over a physical conducting path between the source and the victim, such as wires, enclosures, ground planes, and so forth. Inductive coupling occurs when two circuits are magnetically coupled. Capacitive cou-

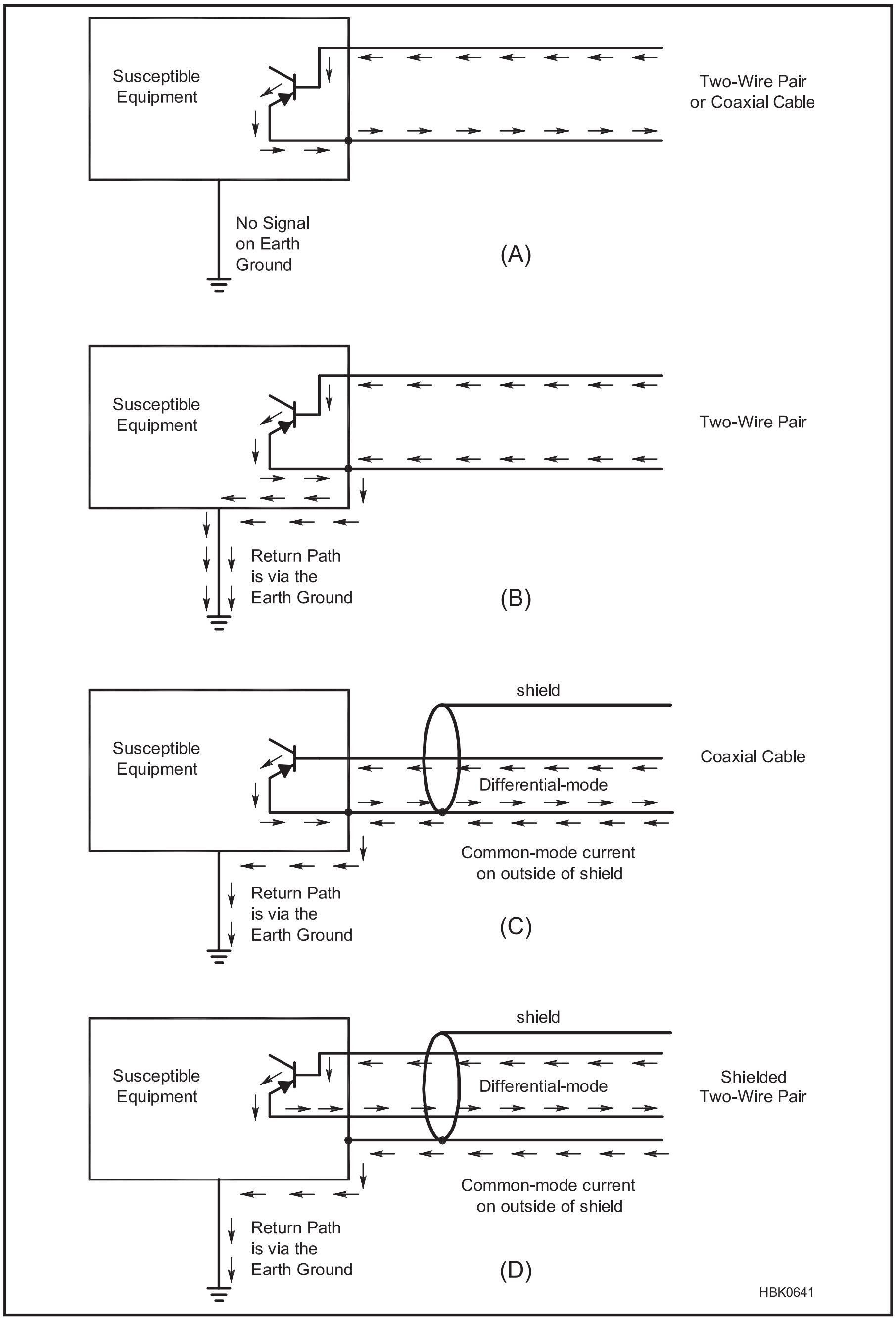


Fig 27.3 — Typical configurations of common-mode and differential-mode current. The drawing in A shows the currents of a differential-mode signal while B shows a common-mode signal with currents flowing equally on all of the source wires. In C, a common-mode signal flows on the outside of a coaxial cable shield with a differential-mode signal inside the cable. In D, the differential-mode signal flows on the internal wires while a common-mode signal flows on the outside of the cable shield.

pling occurs when two circuits are coupled electrically through capacitance. Typical RFI problems you are likely to encounter often include multiple paths, such as conduction and radiation. (See the section Shields and Filters, also Ott, sections 2.1-2.3.)

27.3.2 Differential-Mode vs Common-Mode Signals

The path from source to victim almost always includes some conducting portion, such as wires or cables. RF energy can be conducted directly from source to victim, be conducted onto a wire or cable that acts as an antenna where it is radiated, or be picked up by a conductor connected to the victim that acts like an antenna. When the noise signal is traveling along the conducted portion of the path, it is important to understand the differences between *differential-mode* and *common-mode* conducted signals (see **Fig 27.3**).

Differential-mode currents usually have two easily identified conductors. In a two-wire transmission line, for example, the signal leaves the generator on one wire and returns on the other. When the two conductors are in close proximity, they form a transmission line and the two signals have opposite polarities as shown in Fig 27.3A. Most desired signals, such as the TV signal inside a coaxial cable or an Ethernet signal carried on CAT5 network cable, are conducted as differential-mode signals.

A common-mode circuit consists of several wires in a multi-wire cable acting as if they were a single current path as in Fig 27.3B. Common-mode circuits also exist when the outside surface of a cable's shield acts as a conductor as in Figs 27.3C and 27.3D. (See the chapter on **Transmission Lines** for a discussion about isolation between the shield's inner and outer surfaces for RF signals.) The return path for a common-mode signal often involves earth ground.

27.3.3 Types of RFI

There are four basic types of RFI that apply to Amateur Radio. The first two occur in the following order of likelihood when the interfering source is an amateur transmitter intentionally generating a radio signal:

1) Fundamental Overload — Disruption or degradation of a device's function in the presence of a transmitter's fundamental signal (the intended signal from the transmitter).

2) Spurious Emissions — Reception of a radio signal interfered with by spurious emissions from the transmitter as defined in the previous section on Part 97 definitions and Fig 27.1.

The second two types of RFI occur, again in order of likelihood, when the reception of a desired signal is interfered with by RF energy received along with the desired signal.

3) External Noise Sources — Reception of a radio signal interfered with by RF energy transmitted incidentally or unintentionally by a device that is not a licensed transmitter

4) Intermodulation — Reception of a radio signal interfered with by intermodulation distortion (IMD) products generated inside or outside of the receiver

As an RFI troubleshooter, start by determining which of these is involved in your interference problem. Once you know the type of RFI, selecting the most appropriate cure for the problem becomes much easier.

27.3.4 Spurious Emissions

All transmitters generate some (hopefully few) RF signals that are outside their intended transmission bandwidth — out-of-band emissions and spurious emissions as illustrated in Fig 27.1. Out-of-band signals result from distortion in the modulation process or consist of broadband noise generated by the transmitter's oscillators that is added to the intended signal. Harmonics, the most common spurious emissions, are signals at integer multiples of the operating (or fundamental) frequency.

Transmitters may also produce broadband noise and/or parasitic oscillations as spurious emissions. (Parasitic oscillations are discussed in the **RF Power Amplifiers** chapter.) Overdriving an amplifier often creates spurious emissions. Amplifiers not meeting FCC certification standards but sold illegally are frequent sources of spurious emissions.

Regardless of how the unwanted signals are created, if they cause interference, FCC regulations require the operator of the transmitter to correct the problem. The usual cure is to adjust or repair the transmitter or use filters at the transmitter output to block the spurious emissions from being radiated by the antenna.

27.3.5 Fundamental Overload

Most cases of interference caused by an amateur transmission are due to *fundamental overload*. The world is filled with RF signals. Properly designed radio receivers of any sort should be able to select the desired signal, while rejecting all others. Unfortunately, because of design deficiencies such as inadequate shields or filters, some radio receivers are unable to reject strong out-of-band signals. Electronic equipment that is not a radio receiver can also suffer from fundamental overload from similar design shortcomings. Both types of fundamental overload are common in consumer electronics.

A strong signal can enter equipment in several different ways. Most commonly, it is conducted into the equipment by connecting wires and cables. Possible RFI conductors include antennas and feed lines, interconnecting cables, power cords, and ground wires. TV antennas and feed lines, telephone or speaker wiring and ac power cords are the most common points of entry.

If the problem is a case of fundamental overload, significant improvement can often be observed just by moving the victim equipment and the signal source farther away from each other. The effect of an interfering signal is directly related to its strength, diminishing with the square of the distance from the source. If the distance from the source doubles, the strength of the electromagnetic field decreases to one-fourth of its power density at the original distance from the source. An attenuator is often a weapon of choice when encountering this type of problem. Reducing the level of the offending strong signal returns the receiver to normal operation and causes the undesirable effects to disappear. This characteristic can often be used to help identify an RFI problem as fundamental overload. If reducing the strength of the signal source causes the same effect that is also a signature of fundamental overload.

27.3.6 External Noise Sources

Most cases of interference to the Amateur Service reported to the FCC are eventually determined to involve some sort of external noise source, rather than signals from a radio transmitter. Noise in this sense means an RF signal that is not essential to the generating device's operation. The most common external noise sources are electrical, primarily power lines. Motors and switching equipment can also generate electrical noise.

External noise can also come from unlicensed Part 15 RF sources such as computers and networking equipment, video games, appliances, and other types of consumer electronics. Regardless of the source, if you determine the problem to be caused by external noise, elimination of the noise must take place at the source. As an alternative, several manufacturers also make noise canceling devices that can help in some circumstances.

27.3.7 Intermodulation Distortion

As discussed in the chapter on **Receivers**, intermodulation distortion (IMD) is caused by two signals combining in such a way as to create *intermodulation products* — signals at various combinations of the two original frequencies. The two original signals may be perfectly legal, but the resulting *intermodulation distortion products* may occur on the frequencies used by other signals and cause interference in the same way as a spurious signal from a transmitter. Depending on the nature of the generating signals, "intermod"

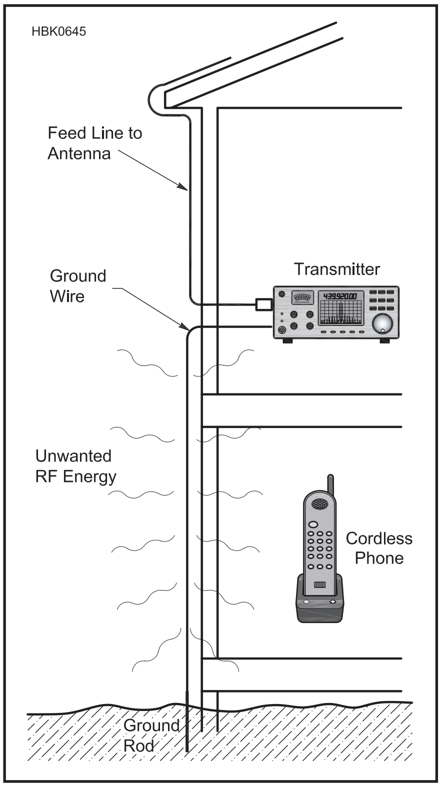


Fig 27.4 — An earth ground connection can radiate signals that might cause RFI to nearby equipment. This can happen if the ground connection is part of an antenna system or if it is connected to a coaxial feed line carrying RF current on the outside of the shield.

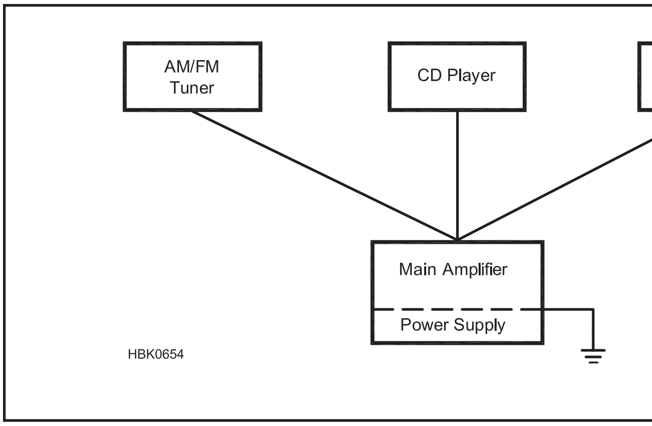


Fig 27.5 — A single-point or star ground eliminates ground loops in a multiple-component system.

can be intermittent or continuous. IMD can be generated inside a receiver by large signals or externally by signals mixing together in non-linear junctions or connections.

27.3.8 Ground Connections

An electrical ground is not a huge sink that somehow swallows noise and unwanted signals. Ground is a *circuit* concept, whether the circuit is small, like a radio receiver, or large, like the propagation path between a transmitter and cable-TV installation. Ground forms a universal reference point between circuits.

While grounding is not a cure-all for RFI problems, ground is an important safety component of any electronics installation. It is part of the lightning protection system in your station and a critical safety component of your house wiring. Any changes made to a grounding system must not compromise these important safety considerations. Refer to the **Safety** chapter for important information about grounding.

Many amateur stations have several connections referred to as "grounds"; the required safety ground that is part of the ac wiring system, another required connection to earth for lightning protection, and perhaps another shared connection between equipment for RFI control. These connections can interact with each other in ways that are difficult to predict.

Rearranging the station ground connections may cure some RFI problems in the station by changing the RF current distribution so that the affected equipment is at a low-impedance point and away from RF "hot spots." Creating a low-impedance connection between your station's equipment is easy to do and will help reduce voltage differences (and current flow) between pieces of equipment. However, a station ground is not always the cure-all that some literature has suggested.

LENGTH OF GROUND CONNECTIONS

The required ground connection for lightning protection between the station equipment and an outside ground rod is at least several feet long in most practical installations. (See the **Safety** chapter for safety and lightning protection ground requirements.)

In general, however, a long connection to earth should be considered as part of an RFI problem only to the extent that it is part of the antenna system. For example, should a long-wire HF antenna end in the station, a ground connection of *any* length is a necessary and useful part of that antenna and will radiate RF.

At VHF a ground wire can be several wavelengths long — a very effective antenna for any harmonics that could cause RFI! For example, in **Fig 27.4**, signals radiated from the required safety ground wire could very easily create an interference problem in the downstairs electronic equipment.

GROUND LOOPS

A *ground loop* is created by a continuous conductive path around a series of equipment enclosures. While this does create an opportunity for lightning and RFI susceptibility, the ground loop itself is rarely a cause of problems at RF. Ground loops are usually associated with problems of audio hum or buzz caused by coupling to power-frequency magnetic fields and currents. To avoid low-frequency ground-loop issues, use short, properly-shielded cables that are the minimum length required to connect the equipment and bundle them together to minimize the area of any enclosed loop. Ground-loop problems at RF are minimized by the use of a single-point or star ground system as shown in **Fig 27.5**.

27.4 Identifying the Type of RFI Source

It is useful to place an offending noise source into one of several broad categories at the early stages of any RFI investigation. Since locating and resolution techniques can vary somewhat for each type, the process of locating and resolving RFI problems should begin with identifying the general type of RFI source.

It is often impossible to identify the exact type of device generating the RFI from the sound of the interference. Because there are many potential sources of RFI, it is often more important to obtain and interpret clues from the general noise characteristics and the patterns in which it appears.

A source that exhibits a repeatable pattern during the course of a day or week, for example, suggests something associated with human activity. A sound that varies with or is affected by weather suggests an outdoor source. Noise that occurs in a regular and repeating pattern of peaks and nulls as you tune across the spectrum, every 50 kHz for example, is often associated with switchmode power supply or similar pulsed-current devices. A source that exhibits fading or other sky wave characteristics suggests something that is not local. A good ear and careful attention to detail will often turn up some important clues. A detailed RFI log can often help, especially if maintained over time.

Noise can be characterized as broadband or narrowband — another important clue. *Broadband noise* is defined as noise having a bandwidth much greater than the affected receiver's operating bandwidth and is reasonably uniform across a wide frequency range. Noise from arcs and sparks, such as power-line noise, tend to be broadband. *Narrowband noise* is defined as noise having a bandwidth less than the affected receiver's bandwidth. Narrowband noise is present on specific, discrete frequencies or groups of frequencies, with or without additional modulation. In other words, if you listened to the noise on an SSB receiver, tuning would cause its sound to vary, just like a regular signal. Narrowband noise often sounds like an unmodulated carrier with a frequency that may drift or suddenly change. Microprocessor clock harmonics, oscillators and transmitter harmonics are all examples of narrowband noise.

Keeping an RFI Log

The importance of maintaining a good and accurate RFI log cannot be overstated. Be sure to record time and weather conditions. Correlating the presence of the noise with periods of human activity and weather often provide very important clues when trying to identify power-line noise. It can also be helpful in identifying noise that is being propagated to your station via sky wave. A log showing the history of the noise can also be of great value should professional services or FCC involvement become necessary at some point.

27.4.1 Identifying Noise from Part 15 Devices

The most common RFI problem reported to the ARRL comes from an unknown and unidentified source. Part 15 devices and other consumer equipment noise sources are ubiquitous. Although the absolute signal level from an individual noise source may be small, their increasing numbers makes this type of noise a serious problem in many suburban and urban areas. The following paragraphs describe several common types of electronic noise sources.

Electronic devices containing oscillators, microprocessors, or digital circuitry produce RF signals as a byproduct of their operation. The RF noise they produce may be radiated from internal wiring as a result of poor shielding. The noise may also be conducted to external, unshielded or improperly shielded wiring as a common-mode signal where it radiates noise. Noise from these devices is usually narrowband that changes characteristics (frequency, modulation, on-off pattern) as the device is used in different ways.

Another major class of noise source is equipment or systems that control or switch large currents. Among them are variable-speed motors in products as diverse as washing machines, elevators, and heating and cooling systems. Charging regulators and control circuitry for battery and solar power systems are a prolific source of RF noise. So are switchmode power supplies for computers and low-voltage lighting. This type of noise is only present when the equipment is operating.

Switchmode supplies, solar controllers and inverters often produce noise signals every N kHz, with N typically being from 5 to 50 or more kHz, the frequency at which current is switched. This is different from noise produced by spark or arc sources that is uniform across a wide bandwidth. This pattern is often an important clue in distinguishing switching noise from power-line or electrical noise.

Wired computer networks radiate noise directly from their unshielded circuitry and from network and power supply cables. The noise takes two forms — broadband noise and modulated carriers at multiple frequencies within the amateur bands. As an example, Ethernet network interfaces often radiate signals heard on a receiver in CW mode. 10.120, 14.030, 21.052 and 28.016 MHz have been reported as frequencies of RFI from Ethernet networks. Each network interface uses its own clock, so if you have neighbors with networks you'll hear a cluster of carriers around these frequencies, ±500 Hz or so.

In cable TV systems video signals are converted to RF across a wide spectrum and distributed by coaxial cable into the home. Some cable channels overlap with amateur bands, but the signals should be confined within the cable system. No system is perfect, and it is common for a defective coax connection to allow leakage to and from the cable. When this happens, a receiver outside the cable will hear RF from the cable and the TV receiver may experience interference from local transmissions. Interference to and from cable TV signals is discussed in detail later in this chapter.

27.4.2 Identifying Power-line and Electrical Noise

POWER-LINE NOISE

Next to external noise from an unknown source, the most frequent cause of an RFI problem reported to the ARRL involving a known source is power-line noise. (For more information on power-line noise, see the book *AC Power Interference Handbook*, by Marv Loftness KB7KK.) Virtually all power-line noise originating from utility equipment is caused by spark or arcing across some hardware connected to or near a power line. A breakdown and ionization of air occurs and current flows across a gap between two conductors, creating RF noise as shown in **Fig 27.6**. Such noise is often referred to as "gap noise" in the utility power industry. The gap may be caused by broken, improperly installed or loose hardware. Typical culprits include insufficient and inadequate hardware spacing such as a gap between a ground wire and a staple. Contrary to common misconception, corona discharge is rarely, if ever, a source of power-line noise.

While there may not be one single conclusive test for power-line noise, there are a number of important tell-tale signs. On an AM or SSB receiver, the characteristic raspy buzz or frying sound, sometimes changing in intensity as the arc or spark sputters a bit, is often the first and most obvious clue.

Power-line noise is typically a broadband type of interference, relatively constant across a wide spectrum. Since it is broadband noise, you simply can't change frequency to eliminate it. Power-line noise is usually, but not al-

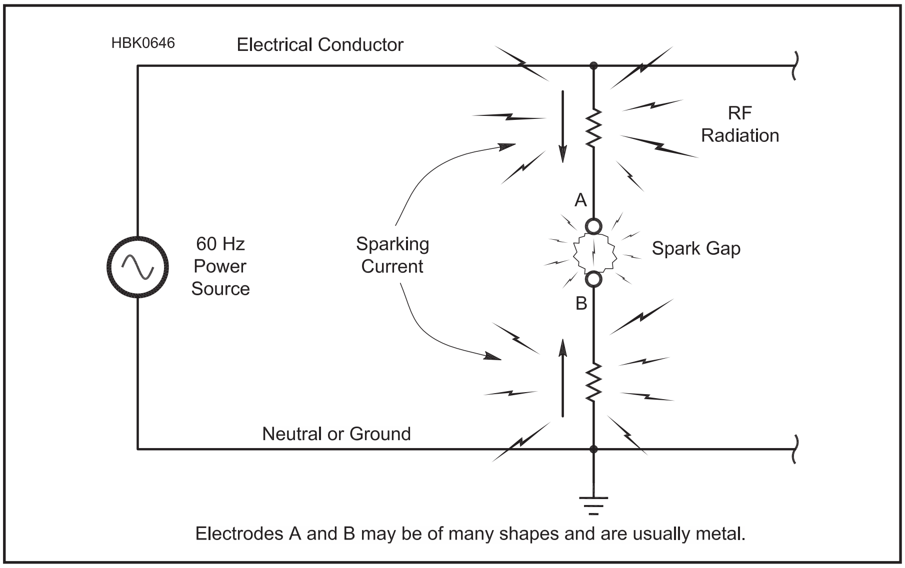


Fig 27.6 — The gap noise circuit on a power line — simplified. (From Loftness, *AC Power Interference Handbook*)

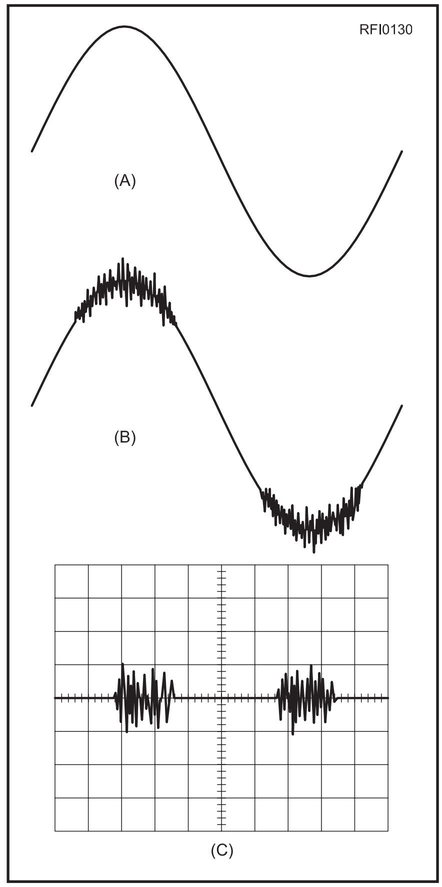


Fig 27.7 — The 60-Hz signal found on quiet power lines is almost a pure sine wave, as shown in A. If the line, or a device connected to it, is noisy, this will often add visible noise to the power-line signal, as shown in B. This noise is usually strongest at the positive and negative peaks of the sine wave where line voltage is highest. If the radiated noise is observed on an oscilloscope, the noise will be present during the peaks, as shown in C.

ways, stronger on lower frequencies. It occurs continuously across each band and up through the spectrum. It can cause interference from the AM broadcast band through UHF, gradually tapering off as frequency increases. If the noise is not continuous across all of an amateur band, exhibits a pattern of peaks and nulls at different frequencies, or repeats at some frequency interval, you probably do not have power-line noise.

The frequency at which power-line noise diminishes can also provide an important clue as to its proximity. The closer the source, the higher the frequency at which it can be received. If it affects VHF and UHF, the source is relatively close by. If it drops off just above or within the AM broadcast band, it may be located some distance away — up to several miles.

Power-line noise is often affected by weather if the source is outdoors. It frequently changes during rain or humid conditions, for example, either increasing or decreasing in response to moisture. Wind may also create fluctuations or interruptions as a result of line and hardware movement. Temperature effects can also result from thermal expansion and contraction.

Another good test for power-line noise requires an oscilloscope. Remember that power-line noise occurs in bursts most frequently at a rate of 120 bursts per second and sometimes at 60 bursts per second. Observe the suspect noise from your radio's audio output. (Note: The record output jack works best if available). Use the AM mode with wide filter settings and tune to a frequency without a station so the noise can be heard clearly. Use the LINE setting of the oscilloscope's trigger subsystem to synchronize the sweep to the line. Power-line noise bursts will remain stable on the display and should repeat every 8.33 ms (a 120-Hz repetition rate) or less commonly, 16.67 ms (60 Hz), if the gap is only arcing once per cycle. (This assumes the North American power-line frequency of 60 Hz.) See **Fig 27.7** for an explanation. If a noise does not exhibit either of these characteristics, it is probably not power-line noise.

If a local TV station is transmitting analog TV signals on a lower VHF channel (very few remain as of early 2013), additional clues may be obtained by viewing the noise pattern on an analog TV set using an antenna (not a cable TV connection). Power-line noise usually appears as two horizontal bars that drift slowly upward on the screen through the picture. (This is due to the difference between the NTSC signal's 59.94 Hz field rate and the 60 Hz power-line frequency.) As one bar rolls off the screen at the top of the display, a new one simultaneously forms at the bottom. In cases where the noise is occurring at 60 bursts per second, there will be only one bar on the display. In addition, the power-line noise bursts may have slightly different characteristics at the positive and negative peaks. This can cause each half of the cycle to have a slightly different pattern on the screen.

ELECTRICAL NOISE

Electrical noise sounds like power-line noise, but is generally only present in short bursts or during periods when the generating equipment or machinery is in use. Noise that varies with the time of day, such as daytime-only or weekends-only, usually indicates some electrical device or appliance being used on a regular basis and not power-line noise. Unless it is associated with climate control or HVAC system, an indoor RFI source of electrical noise less likely to be affected by weather than power-line noise.

ELECTRIC FENCES

A special type of electrical noise that is easy to identify is the "pop…pop…pop" of an electric fence. High voltage is applied to the fence about once a second by a charging unit. Arcs will occur at corroded connections in the fence, such as at a gate hook or splice. If brush or weeds touch the fence, the high-voltage will cause an arc at those points until the vegetation burns away (the arc will return when the vegetation re-grows). Each arc results in a short burst of broadband noise, received as a "tick" or "pop" in an HF receiver.

27.4.3 Identifying Intermodulation Distortion

Intermodulation distortion (IMD) often occurs within a receiver when two strong signals

combine to produce intermodulation products that can interfere with a desired signal. Since the products are generated internally to the receiver, the strong signals must be filtered out or attenuated before they can enter the receiver circuits in which IMD products are generated.

Mixing of signals can also occur in any non-linear junction where the original signals are both strong enough to cause current to flow in the junction. This is a particular problem at multi-transmitter sites, such as broadcast facilities and industrial or commercial communications sites. Non-linear junctions can be formed by loose mechanical contacts in metal hardware, corroded metal junctions, and by semiconductor junctions connected to wires that act as antennas for the strong signals. Non-linear junctions also detect or demodulate RF signals to varying degrees, creating interfering audio or dc signals in some cases. IMD products generated externally cannot be filtered out at the receiver and must be eliminated where the original signals are being combined.

An intermodulation product generated externally to a receiver often appears as an intermittent transmission, similar to a spurious emission. (See the **Receivers** chapter for more information on intermodulation.) It is common for strong signals from commercial paging or dispatch transmitters sharing a common antenna installation to combine and generate short bursts of voice or data signals. AM broadcast transmissions can combine to produce AM signals with the modulation from both stations audible.

Like external intermodulation products, those generated by a receiver acting non-linearly appear as combinations of two or more strong external signals. For example, intermodulation from two SSB or FM voice signals produces somewhat distorted signals with the modulating signals of both stations. Since the two signals are not synchronized, the intermodulation products come and go unpredictably, present only when both of the external signals are present.

Intermodulation within a receiver can often be detected simply by activating the receiver's incoming signal attenuator. If attenuating the incoming signals causes the intermodulation product to by reduced in strength by a greater amount than that of the applied attenuation, intermodulation in the receiver is a strong possibility. Since receivers vary in their IMD performance, differences in the interfering signal strength between receivers is also an indication of intermodulation.

The following simple "attenuator test" can be used to identify an IMD product, even in cases where it appears similarly in multiple receivers:

- If your receiver does not have one, install a step attenuator at its RF input. If you use an attenuator internal to your receiver, it must attenuate the RF at the receiver's input.
- Tune the receiver to the suspected intermod product with the step attenuator set to 0 dB. Note the signal level.
- Add a known amount of attenuation to the signal. Typically 10 or 20 dB makes a good starting point for this test.
- If the suspect signal drops by more than the amount of added attenuation, the suspect signal is an IMD product. For example, if you add 10 dB of attenuation, and the signal drops by 30 dB, you have identified an IMD product.
- You can also compare the reduction in signal level between the suspect IMD product and a known genuine signal with and without the added attenuation. Use a known genuine signal that is about the same strength as the suspect signal with no added attenuation. If the suspect signal drops by the same as the added attenuation, it is not an IMD product.

Intermodulation distortion can be cured in a number of ways. The goal is to reduce the strength of the signals causing IMD so that the receiver circuits can process them linearly and without distortion.

If IMD is occurring in your receiver, filters that remove the strong unwanted signals causing the IMD while passing the desired signal are generally the best approach since they do not compromise receiver sensitivity. (The chapter on **Receivers** discusses how to add additional filtering to your receiver.) Turning off preamplifiers, adding or increasing the receiver's attenuation, and reducing its RF gain will reduce the signal strength in your receiver. Antenna tuners and external band-pass filters can also act as a filter to reduce IMD from out-of-band signals. Directional beams and antennas with a narrower bandwidth can also help, depending on the circumstances of your particular problem.

IMD can also be created in a broadcast FM or TV receiver or preamplifier. The solutions are the same — add suitable filters or reduce overall signal levels and gain so that the strong interfering signal can be processed linearly.

27.5 Locating Sources of RFI

Locating an offending device or noise source might sometimes seem like trying to find a needle in a haystack. With a little patience and know-how, it is often possible to find the source of a problem in relatively short order. RF detective work is often required and some cases require a little more perseverance than others. In any case, armed with some background and technique, it is often easier to find an offending source than the first-time RFI investigator might expect.

Whenever an unknown source of interference becomes an issue, begin the process of identifying the source by verifying that the problem is external to your radio. Start by removing the antenna connection. If the noise disappears, the source is external to your radio and you are ready to begin hunting for the noise source.

27.5.1 Noise Sources Inside Your Home

Professional RFI investigators and the experiences of the ARRL RFI desk confirm that most RFI sources are ultimately found to be in the complainant's home. Furthermore, locating an in-house source of RFI is so simple it that it makes sense to start an investigation by simply turning off your home's main circuit breaker while listening to the noise with a battery-powered portable radio. (Don't forget that battery-powered equipment may also be a noise source — remove the batteries from consumer devices, as well.) If the noise goes away, you know the source is in your residence. After resetting the breaker, you can further isolate the source by turning off individual breakers one at a time. Once you know the source circuit, you can then unplug devices on that circuit to find it.

CAUTION: ***Do not attempt to remove cartridge fuses or operate exposed or open-type disconnects if it is possible to make physical contact with exposed electrical circuits.***

27.5.2 Noise Sources Outside Your Home

It is often possible to locate a noise source outside your home with a minimum of equipment and effort. Because of Part 15's absolute emissions limits, most Part 15 noise sources are within a few hundred feet of the complainant's antenna. They are also often on the same power transformer secondary system as the complainant. This typically reduces the number of possible residences to relatively few.

If the noise source is not compliant with Part 15 limits, it may be blocks or even thousands of feet from your station.

Electrical noise sources in a home, such as an arcing thermostat or a noisy washing machine controller, can also be tracked down in the same way as noise from consumer electronic devices. Electrical noise from an incidental emitter, such as a power line, can propagate much farther than noise from an otherwise legal unintentional emitter. Some Part 15 devices, battery chargers for electric scooters and wheelchairs, for example, are notorious for exceeding Part 15 absolute emissions limits on conducted noise.

The following procedure can be used to trace a noise source to a private home, town house, apartment, or condominium. The number of homes that could be host to a source generating noise could make searching house by house impractical. In such cases, use noise tracking techniques discussed in the following sections to narrow the search to a more reasonable area.

1) Verify that the noise is active before attempting to locate it. Don't forget this all-important first step. You cannot find the source when it's not present.

2) If possible, use a beam to record bearings to the noise before leaving your residence. Walk or drive through the neighborhood with particular emphasis in the direction of the noise, if known. Try to determine the rough geographic area over which the noise can be heard. If the geographic area over which you can hear the noise is confined to a radius of several hundred feet or less, or it diminishes quickly as you leave your neighborhood, this confirms you are most likely dealing with a Part 15 consumer device.

3) Since the noise will be strongest at an electrical device connected to the residence containing the source, you want to measure the noise at a device common to the exterior of all the potential homes. Suitable devices include electric meters, main service breakers (whether outside or in a utility room), front porch lights, electric lamp posts, outside air conditioner units, or doorbell buttons. Whatever radiator you choose, it should be accessible at each home. The device you select to test as the noise radiator will be referred to in these instructions as the "radiator." Using the same type of device as a test point at each home helps obtain consistent results.

4) You are now ready to compare the relative signal strengths at the radiator on each of the potential source residences. Use a detector suitable to receive the noise, typically a battery-powered receiver. Preferably, the receiver should have a variable RF gain control. An external step attenuator will also work if the antenna is external to the radio. If the antenna can be removed, a probe can also be made from a small piece of wire or paper clip to reduce the receiver's sensitivity. Start by holding the detector about two inches from the radiator at the residence where the noise source may be located. Turn the detector's RF gain control down to a point where you can just barely hear the noise. Alternately, increase the attenuation if using an external step attenuator. Record the RF gain or attenuator setting for each test.

5) Proceed to the next residence. Again hold the detector approximately two inches from the radiator. (The detector should be placed at the same location at each residence, as much as is practical.) Since you had previously set the detector to just barely hear the noise at the residence having the interference problem, you can move on to the next residence if you do not hear the noise. Remember, in order for your detector to hear the noise at then next house, the noise level will have to be the same or higher than the previous location. If you need to increase the detector's sensitivity to be able to hear the noise, you are moving away from the noise source.

6) When you reach the next residence, if the level is lower or not heard, you're moving further from the source. Continue your search to residences in other directions or across the street. If the level is higher, then you're headed in the right direction. Be sure to turn the gain control down to the point of just barely hearing the noise as its strength increases.

7) Continue on to the next house, repeating the previous steps as necessary. The residence with the source will be the one with the strongest noise at the radiator.

Depending on the circumstances of a particular situation, it may be possible to first isolate the power pole to which the source residence is connected. Walk or drive along the power lines in the affected area while listening to the noise with a battery-powered radio. Continue to decrease the receiver's RF gain as the noise gets louder, thus reducing the area over which you can hear it. Finally, isolate the loudest pole by reducing the RF gain to a point at which you can hear it at only one pole. Once the pole has been isolated, look to see which houses are connected to its transformer. Typically this will reduce the number of potential residences to a very small number.

CAUTION: ***Always observe good safety practices! Only qualified people familiar with the hazards of working around energized electrical equipment should inspect power-line or other energized circuitry.***

When attempting to isolate the pole, it is often best to use the highest frequency at which you can hear the noise. Noise can exhibit peaks and nulls along a power line that are a function of its wavelength. Longer wavelengths can therefore make it difficult to pinpoint a particular point along a line. Furthermore, longer wavelength signals typically propagate further along power lines. You can often reduce your search area by simply increasing the frequency at which you look for the noise.

In some cases, tuning upward in frequency can also be used to attenuate noise. This can be especially helpful in cases where your receiver does not have an RF gain control. As mentioned previously, switchmode power supplies typically generate noise that exhibits a regular and repeating pattern of peaks and nulls across the spectrum. While a typical interval might be every 50 kHz or so, the noise will often start to diminish at the highest frequencies. The peaks in some cases might drift over time, but tuning to the highest frequency at which you can hear the noise will often attenuate it enough to help locate it. If the peak drifts however, be sure to keep your receiver set on the peak as you attempt to locate the source.

Under FCC rules, the involved utility is responsible for finding and correcting harmful interference that is being generated by its own equipment. In cases where a utility customer is using an appliance or device that generates noise, the operator of the device is responsible for fixing it — even if the noise is conducted and radiated by the power company's power lines.

27.5.3 Approaching Your Neighbor

Once you identify the source residence and approach your neighbor, the importance of personal diplomacy simply cannot be overstated. The first contact regarding an RFI problem between a ham and a neighbor is often the most important; it is the start of all future relations between the parties. The way you react and behave when you first discuss the problem can set the tone for everything that follows. It is important, therefore, to use a diplomatic path from the very start. A successful outcome can depend upon it!

A self-help guide for the consumer published jointly by the ARRL and the Consumer Electronics Association (CEA) often proves helpful when discussing an interference problem with a neighbor. Entitled *What To Do if You Have an Electronic Interference Problem*, it may be printed and distributed freely. It is available on the ARRL website at **www.arrl.org/information-for-the-neighbors-of-hams** and also on the CD-ROM accompanying this book. Be sure to download and print a copy for your neighbor before you approach him or her.

With the noise active and with a copy of the pamphlet handy, approach your neighbor with a radio in hand, preferably an ordinary AM broadcast or short-wave receiver. Let them hear it but not so loud that it will be offensive. Tell them this is the problem you are experi-

encing and you believe the source may be in their home. Don't suggest what you think the cause is. If you're wrong, it often makes matters worse. Give them the pamphlet and tell them it will only take a minute to determine whether the source is in their home. Most neighbors will agree to help find the source, and if they agree to turn off circuit breakers, it can be found very quickly. Start with the main breaker to verify you have the correct residence, then the individual breakers to find the circuit. The procedure then becomes the same as described for your own residence.

27.5.4 Radio Direction Finding

Radio direction finding (RDF) can be a highly effective method to locate an RFI source although it requires more specialized equipment than other methods. Professional interference investigators almost always use radio direction finding techniques to locate power-line noise sources. See the **Antennas** chapter for more information on direction finding antennas.

A good place to start, whenever possible, is at the affected station. Use an AM receiver, preferably one with a wide IF bandwidth. An RF gain control is particularly helpful but an outboard step attenuator can be a good substitute. If there is a directional beam capable of receiving the noise, use it on highest frequency band at which the noise can be heard using the antenna. If you can hear the noise at VHF or UHF, you'll typically want to use those frequencies for RDF.

Select a frequency at which no other stations or signals are present and the antenna can discern a directional peak in the noise. Rotate the beam as required to get a bearing on the noise, keeping the RF gain at a minimum. Repeat with a complete 360° sweep using the minimum RF gain possible to hear the noise in its loudest direction. Try to decrease the RF gain to a point at which the noise clearly comes from one and only one direction. You can simultaneously increase the AF gain as desired to hear the noise.

Distant sources, including power-line noise, are generally easier to RDF at HF than nearby sources. Whenever possible, it's almost always better to use VHF or UHF when in close proximity to a source. Tracking a source to a specific residence by RDF at HF is sometimes possible. Such factors as balance and geometry of a home's internal wiring, open switch circuits and distance, may cause the residence to appear somewhat as a point source.

If the search is being conducted while mobile or portable, VHF and UHF are t ypically the easiest and most practical antennas. Small handheld Yagi antennas for 2 meters and 440 MHz are readily available and can serve double duty when operating portable. Many handheld receivers can be configured to receive AM on the VHF bands. Be sure to check your manual for this feature. VHF Aircraft band or "Air band" receivers are also a popular choice since they receive AM signals.

Using RDF to locate an HF noise source while in motion presents significant challenges. Conducted emissions are typical from a consumer device or appliance. In this case, the emissions can be conducted outside the residence and on to the power line. The noise can then propagate along neighborhood distribution lines, which in turn acts as an antenna. The noise can often exhibit confusing peaks and nulls along the line, and if in the vicinity of a power line radiating it, RDF can be extremely difficult, if not impossible. Depending on the circumstances, you could literally be surrounded by the near field of an antenna! You would generally want to stay away from power lines and other potential radiators when searching at HF.

Antennas for HF RDF while walking typically include small loops and ferrite rod antennas. In some cases, a portable AM broadcast radio with a ferrite rod antenna can be used for direction finding. An HF dipole made from a pair of whip antennas may be able to be used to get an approximate bearing toward the noise. Mount the dipole about 12 feet above ground (remembering to watch out for overhead conductors!) and rotate to null out the noise. For all three types of antenna, there will be two nulls in opposite directions. Note the direction of the null. Repeat this procedure from another location then triangulate to determine the bearing to the noise.

27.6 Power-line Noise

This chapter's section "Identifying RFI Source Types" describes power-line noise, its causes, and methods to identify it. Power-line noise is a unique problem in several respects. First and foremost, the offending source is never under your direct control. You can't just simply "turn it off" or unplug the offending device. Nor will the source be under the direct control of a neighbor or someone you are likely to know. In the case of power-line noise, the source is usually operated by a company, municipality, or in some cases, a cooperative. Furthermore, shutting down a power line is obviously not a practical option.

Another unique aspect of power-line noise is that it almost always involves a defect of some sort. The cure for power-line noise is to fix the defect. This is almost always a utility implemented repair and one over which you do not have any direct control.

FCC rules specify that that the operator of a device causing interference is responsible for fixing it. Whenever encountering a power-line noise problem, you will be dealing with a utility and won't have the option of applying a relatively simple technical solution to facilitate a cure, as you would if the device were located in your home. Utilities have a mixed record when it comes to dealing with power-line noise complaints. In some cases, a utility will have a budget, well-trained personnel, and equipment to quickly locate and address the problem. In other cases, however, the utility is simply unable to effectively deal with power-line noise complaints or even denies their equipment can cause RFI.

What does this mean for an amateur with a power-line noise complaint? Utilities can be of any size from large corporations to local co-operatives or city-owned systems. Regardless of the category in which your utility may fall, it must follow Part 15 of the FCC rules. Dealing with a company, coop or municipality, however, as opposed to a device in your home, or a nearby neighbor that you know personally, can present its own set of unique challenges. Multiple parties and individuals are often involved, including an RFI investigator, a line crew and associated management. In some cases, the utility may never have received an RFI complaint before yours.

27.6.1 Before Filing a Complaint

Obviously, before filing a complaint with your local utility, it is important to verify the problem as power-line noise as best as possible and verify that it is not caused by a problem with electrical equipment in your home. Other sources, such as lighting devices and motors, can mimic power-line noise, especially to an untrained ear. Don't overlook these important steps. Attempting to engage your utility in the resolution of an RFI problem can not only waste time but can be embarrassing if the source is right in your own home!

Utilities are not responsible for noise generated by customer-operated devices — *even if the noise is being radiated by the power lines.* They are responsible for fixing only that noise which is being generated by their equipment.

27.6.2 Filing a Complaint

Once you have verified the problem to be power-line noise (see this chapter's section on Identifying Power-line and Electrical Noise) and that it is not coming from a source in your home or a nearby residence, contact your utility's customer service department. In addition to your local phone book, customer service phone numbers are included on most power company websites.

It is important to maintain a log during this part of the process. Be sure to record any "help ticket" numbers that may be assigned to your complaint as well as names, dates and a brief description of each conversation you have with electric company personnel. If you identify specific equipment or power poles as a possible noise source, record the address and any identifying numbers on it.

Hopefully, your complaint will be addressed in a timely and professional manner. Once a noise source has been identified, it is up to the utility to repair it within a reasonable period. You and the utility may not agree on what constitutes a reasonable period, but attempt to be patient. If no action is taken after repeated requests, reporting the complaint to the ARRL and requesting assistance may be in order. (Before contacting the ARRL review The Cooperative Agreement, a section of this chapter.)

It is also important to cooperate with utility personnel and treat them with respect. Hostile and inappropriate behavior is almost always counter-productive in these situations. Remember, you want utility and other related personnel to help you — not avoid you. Even if the utility personnel working on your case seem unqualified, hostile behavior has historically never been a particularly good motivator in these situations. In fact, most protracted power-line noise cases reported to the ARRL began with an altercation in the early stages of the resolution process. In no case did it help or expedite correction of the problem.

27.6.3 Techniques for Locating Power-line Noise Sources

Radio direction finding (RDF) techniques typically offer the best and most efficient approach to locating most power-line noise sources. It is the primary method of choice used by professionals. While RDF is usually the most effective method, it also requires some specialized equipment, such as a hand-held beam antenna. Although specialized professional equipment is available for RDF, hams can also use readily available amateur and homebrew equipment successfully. The CD-ROM accompanying this *Handbook* includes some power-line noise locating equipment projects you can build.

Although it is the utility's responsibility to locate a source of noise emanating from its equipment, many companies simply do not possess the necessary expertise or equipment to do so. As a practical matter, many hams have assisted their utility in locating noise sources. In some cases, this can help expedite a speedy resolution.

There is a significant caveat to this approach however. Should you mislead the power company into making unnecessary repairs, they will become frustrated. This expense and time will be added to their repair list. Do not make a guess or suggestions if you don't know what is causing the noise. While some power companies might know less about the locating process than the affected ham, indiscriminate replacement of hardware almost always makes the problem worse. Nonetheless, depending on your level of expertise and the specifics of your situation, you may be able to facilitate a speedy resolution by locating the RFI source for the utility.

27.6.4 Amateur Power-line Noise Locating Equipment

Much of the equipment that an amateur would use to locate power-line noise has previously been described in the "Radio Direction Finding" section. Before discussing how to locate power-line noise sources, here are a few additional equipment guidelines:

Receiver — You'll need a battery-operated portable radio capable of receiving VHF or UHF in the AM mode. Ideally, it should also be capable of receiving HF frequencies, especially if the interference is a problem at HF and not VHF. Some amateurs also use the aircraft band from 108 to 137 MHz. The lower frequencies of this band can sometimes enable an RFI investigator to hear the noise at greater distances than on 2 meters or 70 cm. An RF gain control is essential but an outboard step attenuator can be used as a substitute. A good S-meter is also required.

Attenuator — Even if your receiver has an RF gain control, an additional outboard step attenuator can often be helpful. It can not only minimize the area of a noise search but also provide added range for the RF gain control. As with other RFI sources — you'll need to add more and more attenuation as you approach the source.

VHF/UHF Antennas — You'll need a hand-held directional beam antenna. A popular professional noise-locating antenna is an eight-element Yagi tuned for 400 MHz. Since power-line noise is a broadband phenomenon, the exact frequency is not important. Either a 2 meter or 70 cm Yagi are capable of locating a power-line noise source on a specific power pole.

Although professional grade antennas can cost several hundred dollars, some hams can build their own for a lot less. See the CD-ROM accompanying this book for the article, "Adapting a Three-Element Tape Measure Beam for Power-line Noise Hunting," by Jim Hanson, W1TRC (SK). This low cost and easy to build antenna for locating power-line noise can be adapted for a variety of frequencies and receivers. Commercial 2 meter and 70 cm antennas for portable use are also suitable if a handle is added, such as a short length of PVC pipe.

Before using an antenna for power-line noise locating, determine its peak response frequency. Start by aiming the antenna at a known power-line noise source. Tune across its range and just beyond. Using minimum RF gain control, find its peak response. Label the antenna with this frequency using a piece of tape or marking pen. When using this antenna for noise locating, tune the receiver to this peak response frequency.

If you don't have a VHF or UHF receiver that can receive AM signals, see the CD-ROM accompanying this book for the article, "A Simple TRF Receiver for Tracking RFI," by Rick Littlefield, K1BQT. It describes the combination of a simple 136 MHz beam and receiver for portable RFI tracking.

HF Antennas — Depending on the circumstances of a particular case, a mobile HF whip such as a 7 or 14 MHz model can be helpful. Magnet-mount models are acceptable for temporary use. An RFI investigator can typically get within VHF range by observing the relative strength of the noise from different locations. Driving in a circle centered on the affected station will typically indicate the general direction in which the noise is strongest. As with beam antennas, determine the peak response frequency for best results.

Ultrasonic Pinpointer — Although an ultrasonic pinpointer is not necessary to locate the pole or structure containing the source, some hams prefer to go one more step by finding the offending noise source on that structure. Guidelines for the use of an ultrasonic device are described later in this section.

Professional-grade ultrasonic locators are often beyond the budget of the average ham. Home brewing options however, can make a practical ultrasonic locator affordable in most situations — and make a great weekend project too. See the CD-ROM accompanying this book for "A Home-made Ultrasonic Power Line Arc Detector" by Jim Hanson, W1TRC (SK).

Oscilloscope — A battery-powered portable oscilloscope is only required for signature analysis. See the next section, Signature or Fingerprint Method, for details.

Thermal/Infrared Detectors and Corona Cameras — This equipment is not recommended for the sole purpose of locating

power-line noise sources. It is rare that an RFI source is even detectable using infrared techniques. Although these are not useful tools for locating noise sources, many utilities still use them for such purposes with minimal or no results. Not surprisingly, ARRL experience has shown that these utilities are typically unable to resolve interference complaints in a timely fashion.

27.6.5 Signature or Fingerprint Method

Each sparking interference source exhibits a unique pattern. By comparing the characteristics between the patterns taken at the affected station with those observed in the field, it becomes possible to conclusively identify the offending source or sources from the many that one might encounter. It therefore isn't surprising that a pattern's unique characteristic is often called its "fingerprint" or "signature." See **Fig 27.8** for an example.

This is a very powerful technique and a real money saver for the utility. Even though there may be several different noise sources in the field, this method helps identify only those sources that are actually causing the interference problem. The utility need only correct the problem(s) matching the pattern of noise affecting your equipment.

You as a ham can use the signature method by observing the noise from your radio's audio output with an oscilloscope. Record the pattern by drawing it on a notepad or taking a photograph of the screen. Take the sketch or photograph with you as you hunt for the source and compare it to signatures you might observe in the field.

Professional interference-locating receivers, such as the Radar Engineers Model 240A shown in Fig 27.8B, have a built in oscilloscope display and waveform memory. This is the preferred method used by professional interference investigators. These receivers provide the ability to switch between the patterns saved at the affected station and those from sources located in the field.

Once armed with the noise fingerprint taken at the affected station, you are ready to begin the hunt. If you have a directional beam, use it to obtain a bearing to the noise. If multiple sources are involved, you'll need to record the bearings to each one. Knowing how high in frequency a particular noise can be heard also provides a clue to its proximity. If the noise can be heard at 440 MHz, for example, the source will typically be within walking distance. If it diminishes beginning 75 or 40 meters, it can be up to several miles away.

Since each noise source will exhibit unique characteristics, you can now match this noise "signature" with one from the many sources you may encounter in the investigation. Compare such characteristics as the duration of each noise burst, pulse shape, and number of pulses.

If you have a non-portable oscilloscope, you may still be able to perform signature matching by using an audio recorder. Make a high quality recording of the noise source at your station and at each suspected noise source in the field, using the same receiver if possible. Replay the sounds for signature analysis.

27.6.6 Locating the Source's Power Pole or Structure

Start your search in front of the affected station. If you can hear the noise at VHF or UHF, begin with a handheld beam suitable for these frequencies. As discussed previously, the longer wavelengths associated with the AM broadcast band and even HF, can create misleading "hotspots" along a line when searching for a noise source as shown in **Fig 27.9**.

As a general rule, only use lower frequencies when you are too far away from the source to hear it at VHF or UHF. Generally work with the highest frequency at which the noise can be heard. As you approach the source, keep increasing the frequency to VHF or UHF, depending on your available antennas. Typically, 2 meters and 70 cm are both suitable for isolating a source down to the pole level.

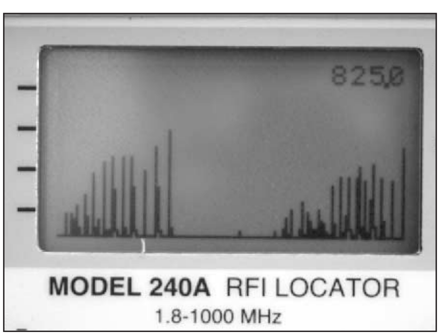
If you do not have an initial bearing to the noise and are unable to hear it with your portable or mobile equipment, start traveling in a circular pattern around the affected station, block-by-block, street-by-street, until you find the noise pattern matching the one recorded at the affected station.

Once in range of the noise at VHF or UHF, start using a handheld beam. You're well on your way to locating the structure containing the source. In many cases, you can now continue your search on foot. *Again, maintain minimum RF gain to just barely hear the noise over a minimum area.* This is important step is crucial for success. If the RF gain is too high, it will be difficult to obtain accurate bearings with the beam.

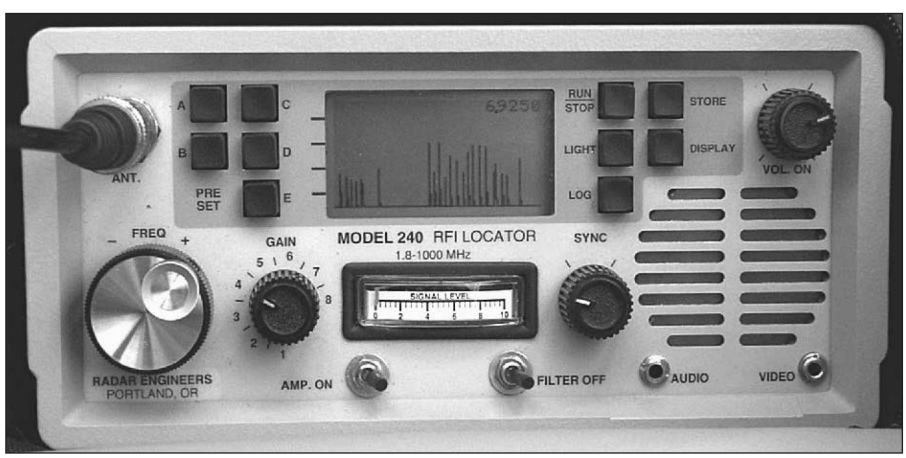
Power-line noise will often be neither vertically nor horizontally polarized but somewhere in between. Be sure to rotate the beam's polarization for maximum noise response. Maintain this same polarization when comparing poles and other hardware.

27.6.7 Pinpointing the Source on a Pole or Structure

Once the source pole has been identified, the next step becomes pinpointing the offending hardware on that pole. A pair of binoculars on a dark night may reveal visible signs of arcing and in some cases you may be able to see other evidence of the problem from



(A)



(B)

Fig 27.8 — An unknown noise source at the complainant's antenna is shown in A. During the RFI investigation, noise signatures not matching this pattern can be ignored, such as shown in B. Once the matching signature originally shown in A is found, the offending noise source has been located.

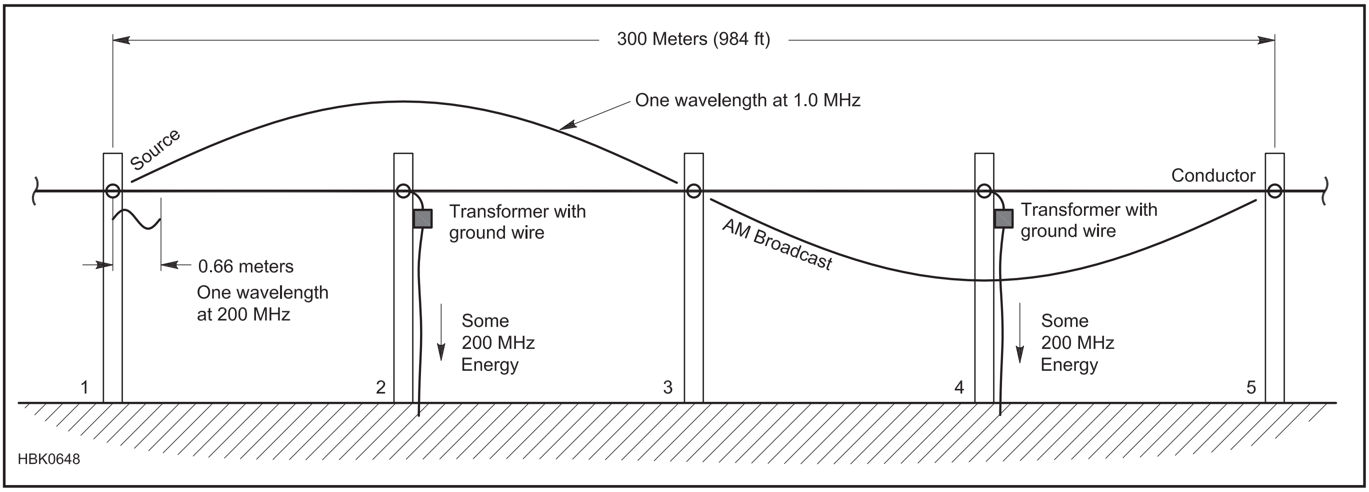


Fig 27.9 — Listening for noise signals on a power distribution line at 1 MHz vs 200 MHz can result in identification of the wrong power pole as the noise source. (From Loftness, *AC Power Interference Handbook*)

the ground. These cases are rare. More than likely, a better approach will be required. Professional and utility interference investigators typically have two types of specialized equipment for this purpose:

- An ultrasonic dish or pinpointer. The RFI investigator, even if not a lineman, can pinpoint sources on the structure down to a component level from the ground using this instrument. See **Fig 27.10**.
- An investigator can instruct the lineman on the use of a hot stick-mounted device used to find the source. This method is restricted to only qualified utility personnel, typically from a bucket truck. See **Fig 27.11**.

Both methods are similar but hams only have one option — the ultrasonic pinpointer.

Caution — Hot sticks and hot stick mounted devices are not for hams! Do not use them. Proper and safe use of a hot stick requires specialized training. In most localities, it is generally unlawful for anyone unqualified by a utility to come within 10 feet of an energized line or hardware. This includes hot sticks.

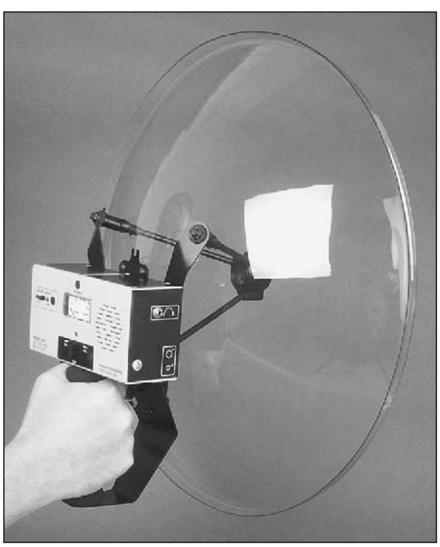


Fig 27.10 — The clear plastic parabolic dish is an "ear" connected to an ultrasonic detector that lets utility personnel listen for the sound of arcs.

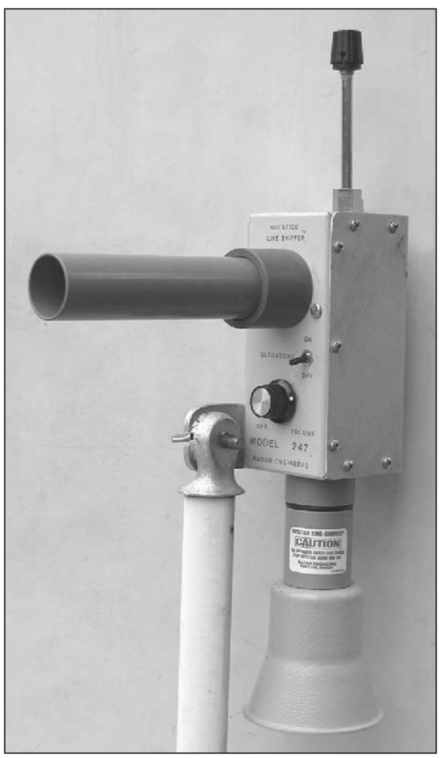


Fig 27.11 — The Radar Engineers Model 247 Hotstick Line Sniffer is an RF and ultrasonic locator. It is used by utility workers to pinpoint the exact piece of hardware causing a noise problem. Mounted on a hotstick, the sniffer is used from the pole or from a bucket.

ULTRASONIC PINPOINTER TIPS

An ultrasonic dish is the tool of choice for pinpointing the source of an arc from the ground. While no hot stick is required, an unobstructed direct line-of-sight path is required between the arc and the dish. This is not a suitable tool for locating the structure containing the source. It is only useful for pinpointing a source once its pole or structure has been determined.

Caveat: Corona discharge, while typically not a source of RF power-line noise, can and often is a significant source of ultrasonic sound. It can often be difficult to distinguish between the sound created by an arc and corona discharge. This can lead to mistakes when trying to pinpoint the source of an RFI problem with an ultrasonic device.

The key to success, just as with locating the structure, is using gain control effectively. Use minimum gain after initially detecting the noise. If the source appears to be at more than one location on the structure, reduce the gain. In part, this will eliminate any weaker noise signals from hardware not causing the problem.

27.6.8 Common Causes of Power-line Noise

The following are some of the more common power-line noise sources. They're listed in order from most common to least common. Note that some of the most common sources are not connected to a primary conductor. This in part is due to the care most utilities take to ensure sufficient primary conductor clearance from surrounding hardware. Note, too, that power transformers do not appear on this list:

- Loose staples on ground conductor
- Loose pole-top pin
- Ground conductor touching nearby hardware

- Corroded slack span insulators
- Guy wire touching neutral
- Loose hardware
- Bare tie wire used with insulated conductor
- Insulated tie wire on bare conductor
- Loose cross-arm braces
- Lightning arrestors

27.6.9 The Cooperative Agreement

While some cases of power-line noise are resolved in a timely fashion, the reality is that many cases can linger for an extended period of time. Many utilities simply do not have the expertise, equipment or motivation to properly address a power-line noise complaint. There are often no quick solutions. Patience can often be at a premium in these situations. Fortunately, the ARRL has a Cooperative Agreement with the FCC that can help. While the program is not a quick or easy solution, it does offer an opportunity and step-by-step course of action for relief. It emphasizes and provides for voluntary cooperation without FCC intervention.

Under the terms of the Cooperative Agreement, the ARRL provides technical help and information to utilities in order to help them resolve power-line noise complaints. It must be emphasized that the ARRL's role in this process is strictly a technical one — it is not in the enforcement business. In order to participate, complainants are required to treat utility personnel with respect, refrain from hostile behavior, and reasonably cooperate with any reasonable utility request. This includes making his or her station available for purposes of observing and recording noise signatures. The intent of the Cooperative Agreement is to solve as many cases as possible before they go to the FCC. In this way, the FCC's limited resources can be allocated where they are needed the most — enforcement.

As the first step in the process, the ARRL sends the utility a letter advising of pertinent Part 15 rules and offering assistance. The FCC then requires a 60-day waiting period before the next step. If by the end of 60 days the utility has failed to demonstrate a good faith effort to correct the problem, the FCC then issues an advisory letter. This letter allows the utility another 60-day window to correct the problem.

A second FCC advisory letter, if necessary, is the next step. Typically, this letter provides another 20- or 30-day window for the utility to respond. If the problem still persists, a field investigation would follow. At the discretion of the Field Investigator, he or she may issue an FCC Citation or Notice of Apparent Liability (NAL). In the case of an NAL, a forfeiture or fine can result.

It is important to emphasize that the ARRL Cooperative Agreement Program does not offer a quick fix. There are several built-in waiting periods and a number of requirements that a ham must follow precisely. It does however provide a step-by-step and systematic course of action under the auspices of the FCC in cases where a utility does not comply with Part 15. Look for complete details, including how to file a complaint, in the ARRL's Power-line Noise FAQ web page at **www.arrl.org/power-line-noise-faq-page**.

27.7 Elements of RFI Control

27.7.1 Differential- and Common-Mode Signal Control

The path from source to victim almost always includes some conducting portion, such as wires or cables. RF energy can be conducted directly from source to victim, be conducted onto a wire or cable that acts as an antenna where it is radiated, or be picked up by a conductor connected to the victim that acts like an antenna. When the energy is traveling along the conducting portion of its path, it is important to understand whether it is a differential- or common-mode signal.

Removing unwanted signals that cause RFI is different for each of these conduction modes. Differential-mode cures (a high-pass filter, low-pass filter, or a capacitor across the ac power line, for example) do not attenuate common-mode signals. Similarly, a common-mode choke will not affect interference resulting from a differential-mode signal.

It's relatively simple to build a differential-mode filter that passes desired signals and blocks unwanted signals with a high series impedance or presents a low-impedance to a signal return line or path. The return path for common-mode signals often involves earth ground, or even the chassis of equipment if it is large enough to form part of an antenna at the frequency of the RFI. A differential-mode filter is not part of this current path, so it can have no effect on common-mode RFI.

In either case, an exposed shield surface is a potential antenna for RFI, either radiating or receiving unwanted energy, regardless of the shield's quality. In this way, a coaxial cable can act as an antenna for RFI if the victim device is unable to reject common-mode signals on the cable's shield. This is why it is important to connect cable shields in such a way that common-mode currents flowing on the shields are not allowed to enter the victim device.

RFI Email Reflector

A good source of information and help is the RFI email reflector maintained on the contesting.com website (**http://lists.contesting.com/mailman/listinfo/RFI**). Simply subscribing in digest form provides a daily dose of RFI discussion. Before asking your question, however, be sure to check the reflector's searchable archives to see if your topic has been covered recently.

27.7.2 Shields and Filters

Breaking the path between source and victim is often an attractive option, especially if either is a consumer electronics device. Remember, the path will involve one or more of three possibilities — radiation, conduction, and inductive or capacitive coupling. Breaking the path of an RFI problem can require analysis and experimentation in some cases. Obviously you must know what the path is before you can break it. While the path may be readily apparent in some cases, more complex situations may not be so clear. Multiple attempts at finding a solution may be required.

SHIELDS

Shielding can be used to control radiated emissions — that is, signals radiated by wiring inside the device — or to prevent radiated signals from being picked up by signal leads in cables or inside a piece of equipment. Shielding can also be used to reduce inductive or capacitive coupling, usually by acting as an intervening conductor between the source and victim.

Shields are used to set boundaries for radiated energy and to contain electric and magnetic fields. Thin conductive films, copper braid and sheet metal are the most common shield materials for the electric field (capacitive coupling), and for electromagnetic fields (radio waves). At RF, the small skin depth allows thin shields to be effective at these frequencies. Thicker shielding material is needed for magnetic field (inductive coupling) to minimize the voltage caused by induced current. At audio frequencies and below, the higher skin depth of common shield materials is large enough (at 60 Hz, the skin depth for aluminum is 0.43 inches) that high-permeability materials such as steel or mu-metal (a

nickel-iron alloy that exhibits high magnetic permeability) are required.

Maximum shield effectiveness usually requires solid sheet metal that completely encloses the source or susceptible circuitry or equipment. Small discontinuities, such as holes or seams, decrease shield effectiveness. In addition, mating surfaces between different parts of a shield must be conductive. To ensure conductivity, file or sand off paint or other nonconductive coatings on mating surfaces.

The effectiveness of a shield is determined by its ability to reflect or absorb the undesired energy. Reflection occurs at a shield's surface. In this case, the shield's effectiveness is independent of its thickness. Reflection is typically the dominant means of shielding for radio waves and capacitive coupling, but is ineffective against magnetic coupling. Most RFI shielding works, therefore, by reflection. Any good conductor will serve in this case, even thin plating.

Magnetic material is required when attempting to break a low-frequency inductive coupling path by shielding. A thick layer of high permeability material is ideal in this case. Low frequency magnetic fields are typically a very short range phenomenon. Simply increasing the distance between the source and victim may help avoid the expense and difficulty of implementing a shield.

Adding shielding may not be practical in many situations, especially with many consumer products, such as a television. Adding a shield to a cable can minimize capacitive coupling and RF pickup, but it has no effect on magnetic coupling. Replacing parallel-conductor cables (such as zip cord) with twisted-pair is quite effective against magnetic coupling and also reduces electromagnetic coupling.

Additional material on shielding may be found in Chapter 2 of Ott and in the **RF Technique**s chapter of this book.

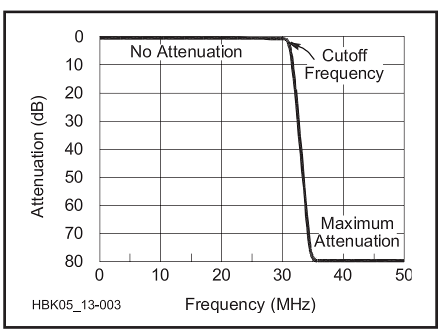


Fig 27.12 — An example of a low-pass filter's response curve.

FILTERS

Filters and chokes can be very effective in dealing with a conducted emissions problem. Fortunately, filters and chokes are simple, economical and easy to try. As we'll see, use of common-mode chokes alone can often solve many RFI problems, especially at HF when common-mode current is more likely to be the culprit.

A primary means of separating signals relies on their frequency difference. Filters offer little opposition to signals with certain frequencies while blocking or shunting others. Filters vary in attenuation characteristics, frequency characteristics and power-handling capabilities. The names given to various filters are based on their uses. (More information on filters may be found in the **RF and AF Filters** chapter.)

Low-pass filters pass frequencies below some cutoff frequency, while attenuating frequencies above that cutoff frequency. A typical low-pass filter curve is shown in **Fig 27.12**. A schematic is shown in **Fig 27.13**. These filters are difficult to construct properly so you should buy one. Many retail Amateur Radio stores that advertise in *QST* stock low-pass filters.

High-pass filters pass frequencies above some cutoff frequency while attenuating frequencies below that cutoff frequency. A typical high-pass filter curve is shown in **Fig 27.14**. **Fig 27.15** shows a schematic of a typical high-pass filter. Again, it is best to buy one of the commercially available filters.

Bypass capacitors can be used to cure differential-mode RFI problems by providing a low-impedance path for RF signals away from the affected lead or cable. A bypass capacitor is usually placed between a signal or power lead and the equipment chassis. If the bypass capacitor is attached to a shielded cable, the shield should also be connected to the chassis. Bypass capacitors for HF signals are usually 0.01 µF, while VHF bypass capacitors are usually 0.001 µF. Leads of bypass capacitors should be kept short, particularly when dealing with VHF or UHF signals.

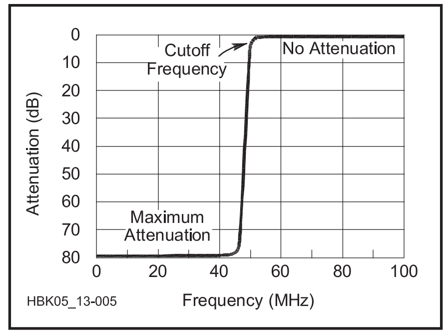


Fig 27.14 — An example of a high-pass filter's response curve.

AC-line filters, sometimes called "brute-force" filters, are used to remove RF energy from ac power lines. Both common-mode and differential-mode noise can be attenuated by a commercially built line filter. A typical sche-matic is shown in **Fig 27.16**. Products from Corcom (**www.corcom.com**) and Delta Electronics (**www.delta.com.tw**) are widely available and well documented on their websites. Morgan Manufacturing (**www.morganmfg.us**) sells stand-alone ac-line filters with ac plugs and sockets, such as the M-473 and M-475 series of AC Line Protectors.

AC-line filters come in a wide variety of sizes, current ratings, and attenuation. In general, a filter must be physically larger to handle higher currents at lower frequencies. The Corcom 1VB1, a compact filter small enough to fit in the junction box for many low

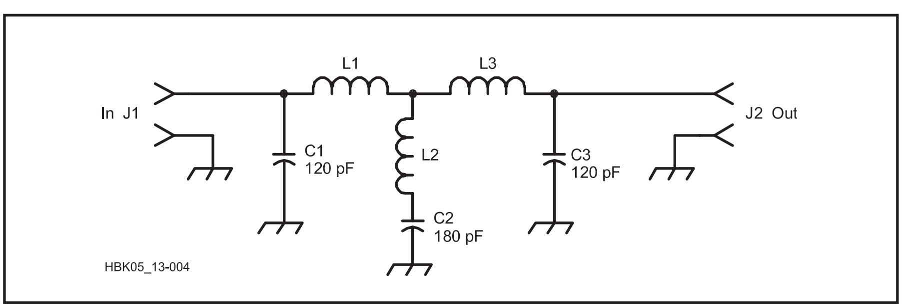


Fig 27.13 — A low-pass filter for amateur transmitting use. Complete construction information appears in the Transmitters chapter of *The ARRL RFI Book*. A high-performance 1.8-54 MHz filter project can be found in the RF and AF Filters chapter of this *Handbook*.

Warning: Bypassing Speaker Leads

Older amateur literature might suggest connecting a 0.01-µ*F capacitor across an amplifier's speaker output terminals to cure RFI from common-mode signals on speaker cables. Don't do this!* Doing so can cause some modern solid-state amplifiers to break into a destructive, full-power, sometimes ultrasonic oscillation if they are connected to a highly capacitive load. Use common-mode chokes and twisted-pair speaker cables instead.

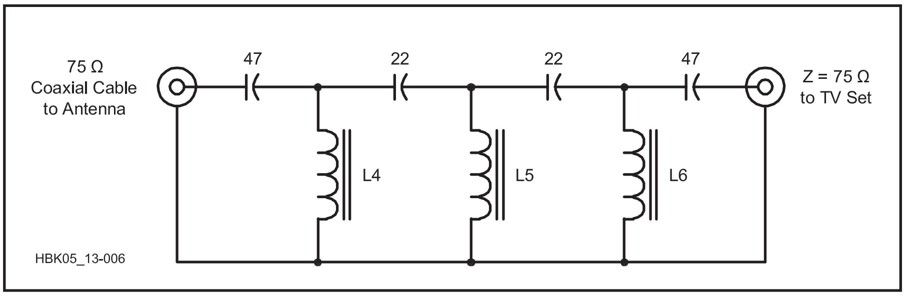


Fig 27.15 — A differential-mode high-pass filter for 75-Ω coaxial cable. It rejects HF signals picked up by a TV antenna or that leak into a cable-TV system. All capacitors are high-stability, low-loss, NP0 ceramic disc components. Values are in pF. The inductors are all #24 AWG enameled wire on T-44-0 toroid cores. L4 and L6 are each 12 turns (0.157 µH) and L5 is 11 turns (0.135 µH).

Fig 27.17 — A common-mode RF choke wound on a toroid core is shown at top left. Several styles of ferrite cores for common-mode chokes are also shown.

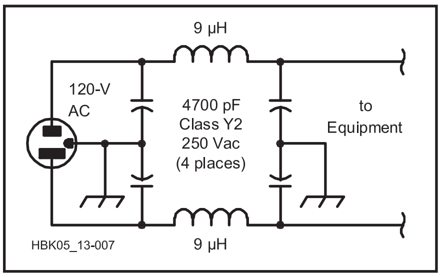


Fig 27.16 — A "brute-force" ac-line filter.

voltage lighting fixtures, provides good common mode attenuation at MF and HF and its 1 A at 250 V ac rating is sufficient for many LV lighting fixtures. In general, you will get more performance from a filter that is physically small if you choose the filter with the lowest current rating sufficient for your application. (Section 13.3 of Ott covers ac-line filters.)

Any wiring between a filter and the equipment being filtered acts as an antenna and forms an inductive loop that degrades the performance of the filter. All such wiring should be as short as possible, and should be twisted. Always bond the enclosure of the filter to the enclosure of the equipment by the shortest possible path. Some commercial filters are built with an integral IEC power socket, and can replace a standard IEC connector if there is sufficient space behind the panel. (IEC is the International Electrotechnical Commission, an international standards organization that has created specifications for power plugs and sockets.) Such a filter is bonded to the chassis and interconnecting leads are shielded by the chassis, optimizing its performance.

A capacitor between line and neutral or between line and ground at the noise source or at victim equipment can solve some RFI problems. ("Chassis ground" in this sense is not "earth," it is the power system equipment ground — the green wire — at the equipment.) Power lines, cords, and cables are often subjected to short-duration spikes of very high voltage (4 kV). Ordinary capacitors are likely

Feed Line Radiation — The Difference Between Balanced and Unbalanced Transmission Lines

The physical differences between balanced and unbalanced feed lines are obvious. Balanced lines are parallel-type transmission lines, such as ladder line or twin lead. The two conductors that make up a balanced line run side-by-side, separated by an insulating material (plastic, air, whatever). Unbalanced lines, on the other hand, are coaxial-type feed lines. One of the conductors (the shield) completely surrounds the other (the center).

In an ideal world, both types of transmission lines would deliver RF power to the load (typically your antenna) without radiating any energy along the way. It is important to understand, however, that both types of transmission lines require a balanced condition in order to accomplish this feat. That is, the currents in each conductor must be equal in magnitude, but opposite in polarity.

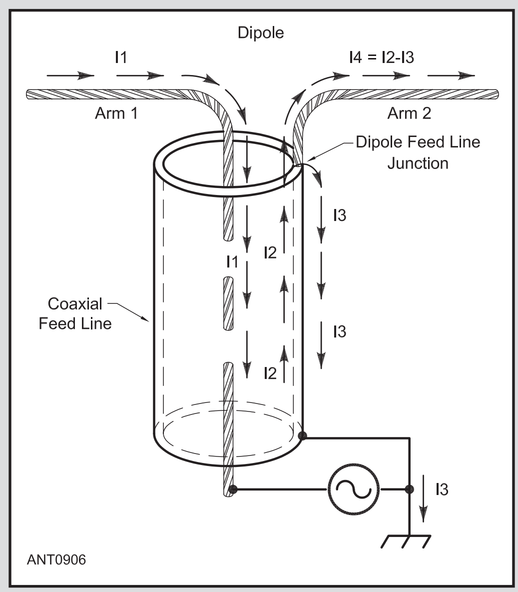


Fig 27.A — Various current paths are present at the feed point of a balanced dipole fed with unbalanced coaxial cable. The diameter of the coax is exaggerated to show the currents clearly.

The classic definition of a balanced transmission line tells us that both conductors must be symmetrical (same length and separation distance) relative to a common reference point, usually ground. It's fairly easy to imagine the equal and opposite currents flowing through this type of feeder. When such a condition occurs, the fields generated by the currents cancel each other-hence, no radiation. An imbalance occurs when one of the conductors carries more current than the other. This additional "imbalance current" causes the feed line to radiate.

Things are a bit different when we consider a coaxial cable. Instead of its being a symmetrical line, one of its conductors (usually the shield), is grounded. In addition, the currents flowing in the coax are confined to the outside portion of the center conductor and the inside portion of the shield.

When a balanced load, such as a resonant dipole antenna, is connected to unbalanced coax, the outside of the shield can act as an electrical third conductor (see **Fig 27.A**). This phantom third conductor can provide an alternate path for the imbalance current to flow. Whether the small amount of stray radiation that occurs is important or not is subject to debate. In fact, one of the purposes of a balun (a contraction of balanced to unbalanced) is to reduce or eliminate imbalance current flowing on the outside of the shield. See the **Transmission Lines** chapter of this book for more information on baluns.

to fail when subjected to these voltages, and the failure could cause a fire. Only Type X1, X2, Y1 and Y2 capacitors should be used on power wiring. AC-rated capacitors can safely handle being placed across an ac line along with the typical voltage surges that occur from time to time. Type X1 and X2 capacitors are rated for use between line and neutral, and are available in values between 0.1 μF and 1 μF. Type X2 capacitors are tested to withstand 2.5 kV, type X1 capacitors are tested to 4 kV. Type Y1 and Y2 capacitors are rated for use between line and ground; Y1 capacitors are impulse tested to 8 kV; Type Y2 to 5 kV. Note that 4700 pF is the largest value permitted to be used between line and ground — larger values can result in excessive leakage currents.

27.7.3 Common-Mode Chokes

Common-mode chokes on ferrite cores are the most effective answer to RFI from a common-mode signal. Differential-mode filters are *not* effective against common-mode signals. (AC-line filters often perform both common- and differential-mode filtering.) Common-mode chokes work differently, but equally well, with coaxial cable and paired conductors. (Additional material on common-mode chokes is found in sections 3.5 and 3.6 of Ott.)

The most common form of common-mode choke is multiple turns of cable wound on a magnetic toroid core, usually ferrite, as shown in **Fig 27.17**. The following explanation applies to chokes wound on rods as well as toroids, but avoid rod cores since they may couple to nearby circuits at HF.

Most of the time, a common-mode signal on a coaxial cable or a shielded, multi-wire cable is a current flowing on the outside of the cable's shield. By wrapping the cable around a magnetic core the current creates a flux in the core, creating a high impedance in series with the outside of the shield. (An impedance of a few hundred to several thousand ohms are required for an effective choke.) The impedance then blocks or reduces the common-mode current. Because equal-and-opposite fields are coupled to the core from each of the differential-mode currents, the common-mode choke has no effect on differential-mode signals inside the cable.

When the cable consists of two-wire, unshielded conductors such as zip cord or twisted-pair, the equal-and-opposite differential currents each create a magnetic flux in the core. The equal-and-opposite fluxes cancel each other and the differential-mode signal experiences zero net effect. To common-mode signals, however, the choke appears as a high impedance in series with the signal: the higher the impedance, the lower the common-mode current.

Warning: Surplus Ferrite Cores

Don't use a core to make a common-mode choke if you don't know what type of material it is made of. Such cores may not be effective in the frequency range you are working with. This may lead to the erroneous conclusion that a common-mode choke doesn't work when a core with the correct material would have done the job.

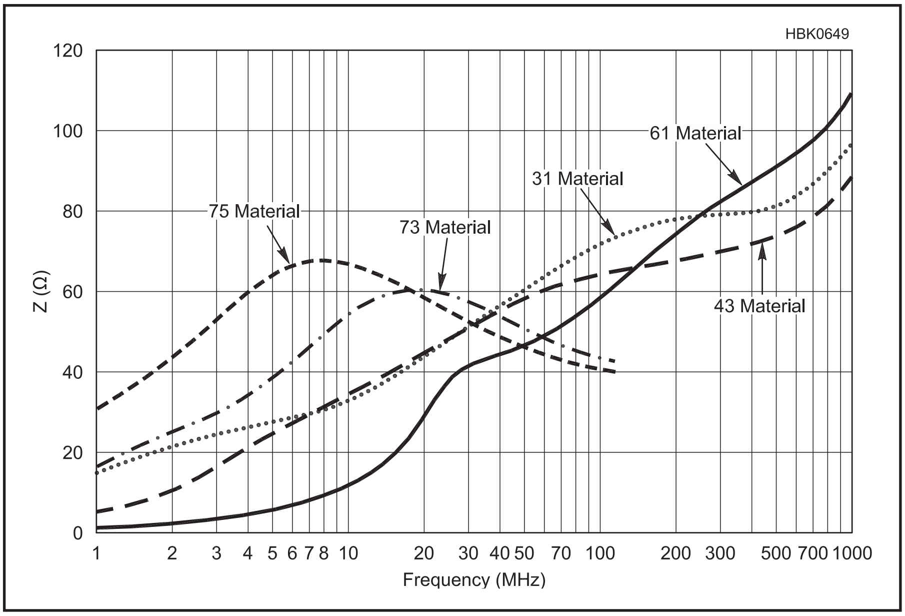


Fig 27.18 — Impedance vs. frequency plots for "101" size ferrite beads illustrate the effect of various ferrite materials across different frequency ranges. A 3.50 mm × 1.30 mm × 6.00 mm bead (Fair-Rite 301 size) was used for the above curve for material comparison, however all materials are not available in all shapes and sizes. Type 73 material is only available in smaller cores, type 31 is only available in larger cores, and type 75 is currently only available as a toroid core. (Graph provided courtesy of the Fair-Rite Corporation)

It is important to note that common-mode currents on a transmission line will result in radiation of a signal from the feed line. (See the sidebar for an explanation of balanced vs unbalanced transmission lines.) The radiated signal can then cause RFI in nearby circuits. This is most common when using coaxial cable as a feed line to a balanced load, such as the dipole in the sidebar. Using a common-mode choke to reduce common-mode feed line currents can reduce RFI caused by signals radiated from the feed line's shield.

The optimum core size and ferrite material is determined by the application and frequency. For example, an ac cord with a plug attached cannot be easily wrapped on a small ferrite core. The characteristics of ferrite materials vary with frequency, as shown by the graph in **Fig 27.18**. Type 31 material is a good all-purpose material for HF and low-VHF applications, especially at low HF frequencies. Type 43 is widely used for HF through VHF and UHF. (See the **Component Data and References** chapter for a table of ferrite materials and characteristics.)

Ferrite beads and clamp-on split cores are also used for EMI control at VHF and UHF, both as common-mode chokes and low-pass filters. (These are essentially single-turn chokes as the cable passes just once through the bead or core.) Multi-turn chokes are required for effective suppression at HF. It is usually more effective to form a common-mode choke by wrapping multiple turns of wire or coaxial cable around a 1- to 2-inch OD core of the correct material.

Common-mode chokes can be used on single conductors unless the desired signal is in the RF spectrum. A common-mode choke creates a high resistive impedance at radio frequencies. At audio frequencies, however, it looks like a relatively small inductance, and is unlikely to have any effect on audio-frequency signals.

27.8 Troubleshooting RFI

Troubleshooting an RFI problem is a multi-step process, and all steps are equally important. First you must determine the type(s) of noise source(s) that are involved. Next, diagnose the problem by locating the noise source and the means by which it creates the noise. The final step is to identify the path by which the noise or signals reach the victim device. Only then can you cure the problem by breaking the path from source to victim.

Each step in troubleshooting an RFI problem involves asking and answering several questions: Is the problem caused by harmonics, fundamental overload, conducted emissions, radiated emissions or a combination of all of these factors? Should it be fixed with a low-pass filter, high-pass filter, common-mode chokes or ac-line filter? How about shielding, isolation transformers, a different ground or antenna configuration? By the time you finish with these questions, the possibilities could number in the millions. You probably will not see your exact problem and cure listed in this book or any other. You must not only diagnose the problem but find a cure as well!

Now that you have learned some RFI fundamentals, you can work on specific technical solutions. A systematic approach will identify the problem and suggest a cure. Most RFI problems can be solved in this way by the application of standard techniques. The following sections suggest specific approaches for different types of common interference problems. This advice is based on the experience of the ARRL RFI Desk, but is not guaranteed to provide a solution to your particular problem. Armed with your RFI knowledge, a kit of filters and tools, your local TC and a determination to solve the problem, it is time to begin. You should also get a copy of the *ARRL RFI Book*. It's comprehensive and picks up where this chapter leaves off.

27.8.1 General RFI Troubleshooting Guidelines

Before diving into the problem, take a step back and consider some of these "pre-troubleshooting steps."

Is It Really EMI? — Before trying to solve a suspected case of EMI, verify that the symptoms actually result from external causes. A variety of equipment malfunctions or external noise can look like interference.

Is It Your Station? — "Your" EMI problem might be caused by another ham or a radio transmitter of another radio service, such as a local CB or police transmitter. If it appears that your station is involved, operate your station on each band, mode and power level that you use. Note all conditions that produce interference. If no transmissions produce the problem, your station *may* not be the cause. (Although some contributing factor may have been missing in the test.) Have your neighbor keep notes of when and how the interference appears: what time of day, what station, what other appliances were in use, what was the weather? You should do the same whenever you operate. If you can readily reproduce the problem with your station, you can start to troubleshoot the problem.

Take One Away — Can you remove the source or victim entirely? The best cure for an RFI problem is often removing the source of the noise. If the source is something broken, for example, the usual solution is to repair it. Power-line noise and an arcing electric fence usually fall into this category. If a switchmode power supply is radiating noise, replace it with a linear supply. Victim devices can sometimes be replaced with a more robust piece of equipment, as well.

Look Around — Aside from the brain, the eyes are a troubleshooter's best tool. Installation defects contribute to many RFI problems. Look for loose connections, shield breaks in a cable-TV installation or corroded contacts in a telephone installation. Have these fixed these first. Look for wiring connected to the victim equipment that might be long enough to be resonant on one or more amateur bands. If so, a common-mode choke may be an easy cure. Ideally you'll generally want place the choke as close to the victim device as practical. If this placement proves too difficult or additional suppression is required, chokes placed at the middle of the wiring may help break up resonances. These are just a few of the possible deficiencies in a home installation.

At Your Station — Make sure that your own station and consumer equipment are clean. This cuts the size of a possible interference problem from your station in half! Once this is done, you won't need to diagnose or troubleshoot your station later. Also, any cures successful at your house may work at your neighbor's as well. If you do have problems in your own home, continue through the troubleshooting steps and specific cures and take care of your own problem first.

Simplify the Problem — Don't tackle a complex system — such as a telephone system in which there are two lines running to 14 rooms — all at once. You could spend the rest of your life running in circles and never find the true cause of the problem.

There's a better way. In our hypothetical telephone system, first locate the telephone jack closest to the telephone service entrance. Disconnect the lines to more remote jacks and connect one RFI-resistant telephone at the remaining jack. (Old-style rotary-dial phones are often quite immune to RF.) If the interference remains, try cures until the problem is solved, then start adding lines and equipment back one at a time, fixing the problems as you go along. If you are lucky, you will solve all of the problems in one pass. If not, at least you can point to one piece of equipment as the source of the problem.

Multiple Causes — Many RFI problems have multiple causes. These are usually the ones that give new RFI troubleshooters the most trouble. For example, consider a TVI problem caused by the combination of harmonics from the transmitter due to an arc in the transmitting antenna, an overloaded TV preamplifier, fundamental overload generating harmonics in the TV tuner, induced and conducted RF on the ac-power connections, and a common-mode signal picked up on the shield of the TV's coaxial feed line. You would never find a cure for this multiple-cause problem by trying only one cure at a time.

In this case, the solution requires that all of the cures be present at the same time. When troubleshooting, if you try a cure, leave it in place even if it doesn't solve the problem. When you add a cure that finally solves the problem entirely, start removing the "temporary" attempts one at a time. If the interference returns, you know that there were multiple causes.

Take Notes — In the process of troubleshooting an RFI problem, it's easy to lose track of what remedies were applied, to what equipment, and in what order. Configurations of equipment can change rapidly when you're experimenting. To minimize the chances of going around in circles or getting confused, take lots of notes as you proceed. Sketches and drawings can be very useful. When you do find the cause of a problem and a cure for it, be sure to write all that down so you can refer to it in the future.

RFI Survival Kit — **Table 27.1** is a list of the material needed to troubleshoot and solve most RFI problems. Having all of these materials in one container, such as a small tackle or craft box, makes the troubleshooting process go a lot smoother.

27.8.2 Transmitters

We start with transmitters not because most interference comes from transmitters, but because your station transmitter is under your direct control. Many of the troubleshooting steps in other parts of this chapter assume that your transmitter is "clean" (free of unwanted RF output).

Start by looking for patterns in the interference. Problems that occur only on harmonics of a fundamental signal usually indicate the transmitter is the source of the interference. Harmonics can also be generated in nearby semiconductors, such as an unpowered VHF

Table 27.1
RFI Survival Kit

Quantity	*Item*
(2)	300-Ω high-pass filter
(2)	75-Ω high-pass filter
(2)	Commercially available clamp-on ferrite cores: #31 and #43 material, 0.3” ID
(12)	Assorted ferrite cores: #31 and #43 material, FT-140 and FT-240 size
(3)	Telephone RFI filters
(2)	Brute-force ac line filters
(6)	0.01-µF ceramic capacitors
(6)	0.001-µF ceramic capacitors

Miscellaneous:
- Hand tools, assorted screwdrivers, wire cutters, pliers
- Hookup wire
- Electrical tape
- Soldering iron and solder (use with caution!)
- Assorted lengths 75-Ω coaxial cable with connectors
- Spare F connectors, male, and crimping tool
- F-connector female-female “barrel”
- Clip leads
- Notebook and pencil
- Portable multimeter

receiver left connected to an antenna, rectifiers in a rotator control box, or a corroded connection in a tower guy wire. Harmonics can also be generated in the front-end components of the TV or radio experiencing interference.

If HF transmitter spurs at VHF are causing interference, a low-pass filter at the transmitter output will usually cure the problem. Install the filter after the amplifier (if used) and before the antenna tuner. (A second filter between the transmitter and amplifier may occasionally help as well.) Install a low-pass filter as your first step in any interference problem that involves another radio service.

Interference from non-harmonic spurious emissions is extremely rare in commercial radios. Any such problem indicates a malfunction that should be repaired.

“Keeping It Simple”

Filters and chokes are the number one weapons of choice for many RFI problems whether the device is the source or the victim. They are relatively inexpensive, easy to install, and do not require permanently modifying the device.

Common-mode choke — Making a common-mode choke is simple. Select the type of core and ferrite material for the frequency range of the interference. (Type 31 is a good HF/low-VHF material, type #43 from 5 MHz through VHF) Wrap several turns of the cable or wire pairs around the toroid. Six to 8 turns is a good start at 10-30 MHz and 10 to 15 turns from 1.8 to 7 MHz. (Ten to 15 turns is probably the practical limit for most cables.) Ferrite clamp-on split cores and beads that slide over the cable or wire are not as effective as toroid-core chokes at HF but are the right solution at VHF and higher frequencies. For a clamp-on core, the cable doesn’t even need to be disconnected from its end. Use type 31 or type 43 material at VHF, type 61 at UHF. At 50 MHz, use two turns through type 31 or 43 cores.

“Brute-Force” ac-line filters — RF signals often enter and exit a device via an ac power connection. “Brute-force” ac-line filters are simple and easy to install. Most ac filters provide both common- and differential-mode suppression. It is essential to use a filter rated to handle the device’s required current.

General installation guidelines for using chokes and filters

1. If you have a brute-force ac-line filter, put one on the device or power cord. If RFI persists, add a common-mode choke to the power cord at the device.
2. Simplify the problem by removing cables one at a time until you no longer detect RFI. Start with cables longer than 1/10th-wavelength at the highest frequency of concern. If the equipment can’t operate without a particular cable, add common-mode chokes at the affected or source device.
3. Add a common-mode choke to the last cable removed and verify its effect on the RFI. Some cables may require several chokes in difficult cases.
4. Begin reconnecting cables one at a time. If RFI reappears, add a common-mode choke to that cable. Repeat for each cable.
5. Once the RFI goes away, remove the common-mode chokes you added one at a time. If the RFI does not return, you do not need to reinstall the choke. If the RFI returns after removing a choke, reinstall it. Keep only those chokes required to fix the problem.

27.8.3 Television Interference (TVI)

An analog TV signal must have about a 45 to 50 dB signal-to-noise ratio to be classified as good-quality viewing. If interference is present due to a single, discrete signal (for example, a CW signal) the signal-to-interference ratio must be 57 dB or greater, depending on the frequency of the interference within the affected channel. Digital TV has somewhat better immunity but for both formats, clear reception requires a strong signal at the TV antenna-input connector so the receiver must be in what is known as a *strong-signal area*.

TVI to a TV receiver (or a video monitor) normally has one of the following causes:

- Spurious signals within the TV channel coming from your transmitter or station.
- The TV set may be overloaded by your transmitter’s fundamental signal.
- Signals within the TV channel from some source other than your station, such as electrical noise, an overloaded mast-mounted TV preamplifier or a transmitter in another service.
- The TV set might be defective or misadjusted, making it look like there is an interference problem.

All of these problems are made potentially more severe because TV receiving equipment is hooked up to *two* antenna systems: (1) the incoming antenna or cable feed line and (2) the ac power line and interconnecting cables. These two antenna systems can couple significant levels of fundamental or harmonic energy into the TV set or video display! The *TVI Troubleshooting Flowchart* in **Fig 27.19** is a good starting point.

The problem could also be caused by direct pickup of the transmitted signal by an unshielded TV or device connected to the TV.

Certain types of television receivers and video monitors are reported to cause broadband RF interference *to* amateur signals — large-screen plasma display models seem to be the most frequent offender — and this may be difficult to cure due to the nature of the display technology. Fortunately, less-expensive, more power-efficient, and RF-quieter LCD technology seems to be displacing plasma technology.

The manufacturer of the TV or video equipment can sometimes help with an interference problem. The Consumer Electronics Association (CEA) can also help you contact equipment manufacturers. Contact them directly for assistance in locating help at **www.ce.org**.

COMMON SOURCES OF TVI

HF transmitters — A nearby HF transmitter is most likely to cause fundamental overload. This is usually indicated by interference to all channels, or at least all VHF channels.

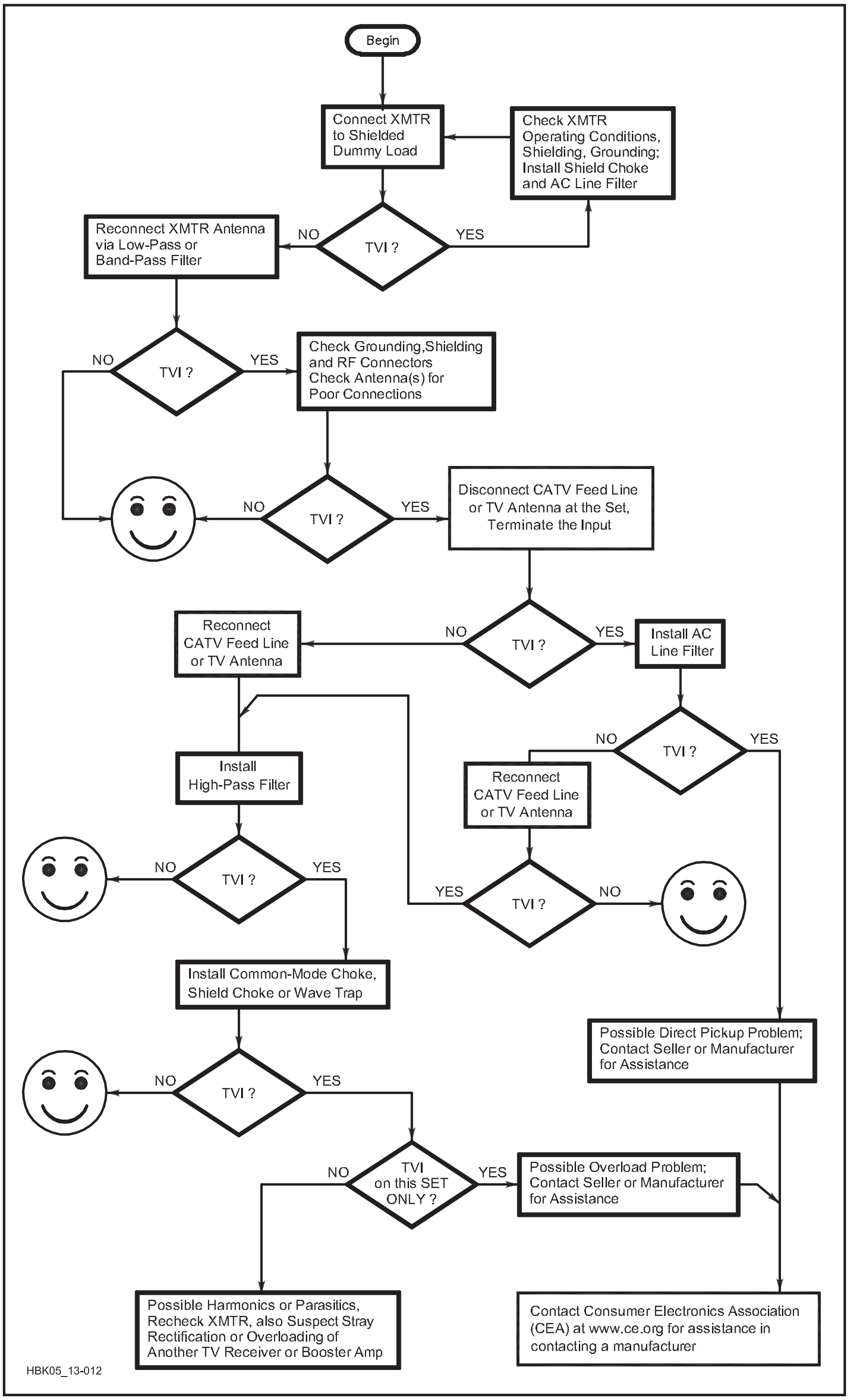


Fig 27.19 — TVI troubleshooting flowchart.

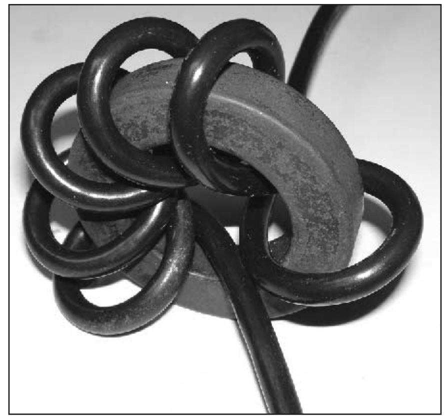


Fig 27.20 — To eliminate HF and VHF signals on the outside of a coaxial cable, use an 1- to 2-inch OD toroid core and wind as many turns of the cable on the core as practical.

To cure fundamental overload from an HF transmitter to an antenna-connected TV, install a high-pass filter directly at the TV set's antenna input. (Do not use a high-pass filter on a cable-TV input because the HF range is used for data and other system signals.)

A strong HF signal can also result in a strong common-mode signal on the TV's feed line. A common-mode choke will block signals on the outside of the feed line shield, leaving the desired signals inside the feed line unaffected. **Fig 27.20** shows how a common-mode choke is constructed for a coaxial feed line.

These two filters can probably cure most cases of TVI! **Fig 27.21** shows a "bulletproof" installation for both over-the-air and cable TV receivers. If one of these methods doesn't cure the problem, the problem is likely direct pickup in which a signal is received by the TV set's circuitry without any conducting path being required. In that case, don't try to fix it yourself — it is a problem for the TV manufacturer.

High-pass filters *should not* be used in a cable TV feed line (Fig 27.21A) with two-way cable devices such as cable modems, set-top boxes, and newer two-way CableCARD-equipped TVs. The high-pass filter may prevent the device from communicating via the cable network's upstream signal path.

VHF Transmitters —Most TV tuners are not very selective and a strong VHF signal, including those from nearby FM and TV transmitters, can overload the tuner easily, particularly when receiving channels 2-13 over the air and not by cable TV. In this case, a VHF notch or stop-band filter at the TV can help by attenuating the VHF fundamental signal that gets to the TV tuner. Winegard (**www.winegard.com**) and Scannermaster (**www.scannermaster.com**) sell tunable notch filters. A common-mode choke may also be necessary if the TV is responding to the common-mode VHF signal present on the TV's feed line.

***TV Preamplifiers* —** Preamplifiers are only needed in weak-signal areas and they often cause trouble, particularly when used unnecessarily in strong-signal areas. They are subject to the same overload problems as TVs and when located on the antenna mast it can be difficult to install the appropriate cures. You may need to install a high-pass or notch filter at the input of the preamplifier, as well as a common-mode choke on the input, output and power-supply wiring (if separate) to effect a complete cure. All filters, connections, and chokes must be weatherproofed. Secure the coax tightly to a metal mast to minimize common-mode current. (Do not secure twin-lead to a metal support.) Use two 1-inch long

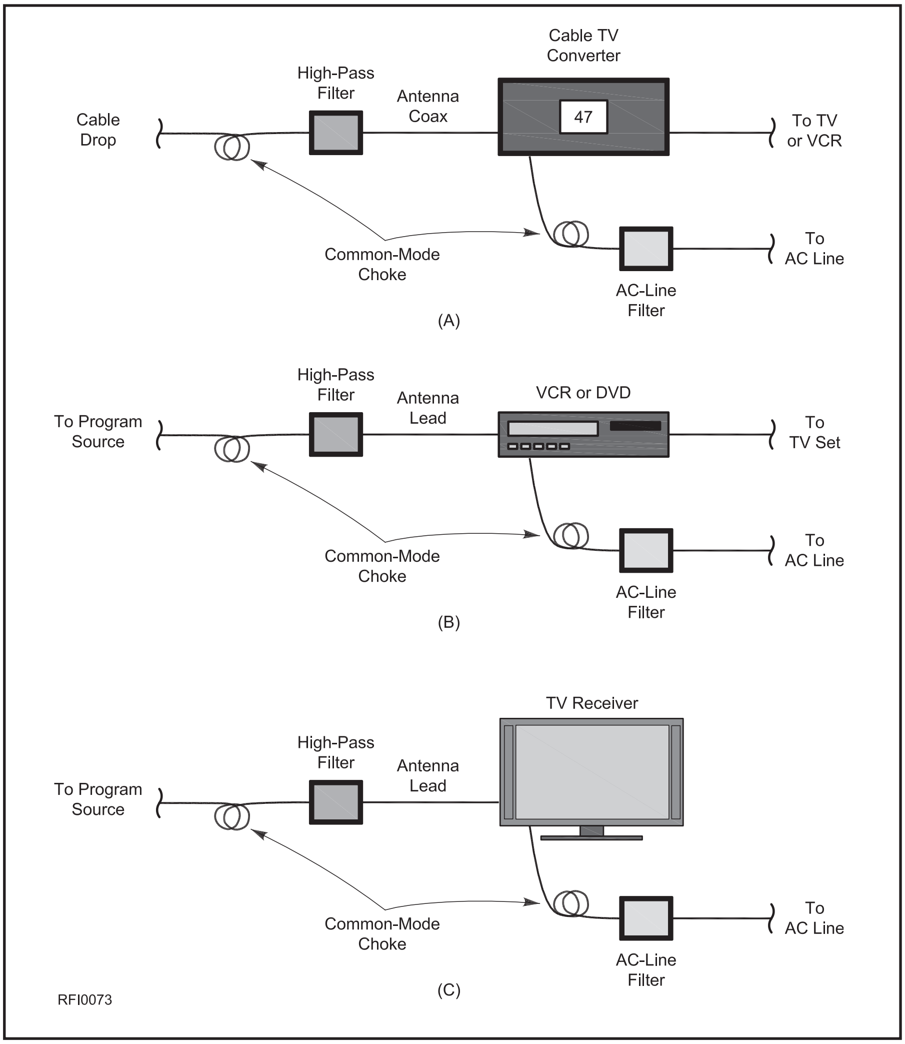


Fig 27.21 — Installing common-mode chokes and high-pass filters will cure most fundamental overload interference from HF sources. This technique does not address direct pickup or spurious emission problems.

type 43 clamp-on ferrite cores if VHF signals are causing the interference and type 61 material for UHF. HF choke design is discussed in the section on Common-Mode Chokes.

Spurious Emissions — You are responsible for spurious emissions produced by your station. If your station is generating any interfering spurious signals, the problem must be cured there. Start by analyzing which TV channels are affected. A TV Channel Chart showing the relationship of the amateur allocations and their harmonics to over-the-air and cable channels is provided on this book's CD-ROM. Each channel is 6 MHz wide. If the interference is only on channels that are multiples of your transmitting frequency, you probably have interference caused by harmonics of your transmitted signal.

It is not certain that these harmonics are coming from your station, however. Harmonics can be generated by overloaded preamplifiers or tuner input circuits. Harmonics can also be generated by non-linear junctions near your station transmitter or very near the TV receiver antenna. (See the section on Intermodulation Distortion.) If your transmitter and station check "clean" — check to see if you have interference on a TV set in your own home — then you must look elsewhere for the source of the harmonics.

Electrical Noise — Digital TV signals are fairly resistant to electrical noise, but in extreme cases can cause the picture to freeze or fail to be displayed as discussed in the following section on Digital TV Receivers. Electrical noise on an analog TV screen generally appears as horizontal bars. Because electrical noise is nearly synchronized with the ac line frequency, these artifacts drift vertically slowly on the screen. Noise from continuous arcing may appear as bright dots anywhere in the picture.

On an AM receiver (including SSB or CW receivers), electrical noise usually sounds like a buzz, sometimes changing in intensity as the arc or spark sputters a bit. If you have a problem with electrical noise, refer to the section on Electrical Noise.

ANALOG TV RECEIVERS

Even though over-the-air TV broadcasting largely switched to a digital format in 2009, millions of analog TV receivers are still in use for cable TV, satellite TV, with converter boxes for digital broadcast signals, and for displaying video from DVDs and other video sources. Older VCR and DVD players may also include an analog TV tuner to receive analog TV signals.

Interference to video displays and monitors that do not receive RF signals from an antenna or RF modulator should be assumed to be common-mode interference or direct pickup. The same applies to interference to a TV set displaying video signals (not through the antenna input). Interference that is present only on the audio is probably a case of common-mode RFI. (See the Stereos and Home Entertainment Systems section of this chapter.)

DIGITAL TV (DTV) RECEIVERS

In 2009, nearly all over-the-air TV broadcasters in the US, with the exception of low-power TV stations and translators, switched from the older NTSC analog format to a new digital format called DTV. The FCC's Digital TV Transition web page (**www.dtv.gov**) has more information on this transition, including an FAQ page. Digital TV signals can operate with much lower signal-to-noise ratios, but are still susceptible to interference.

Interference to digital TV signals from amateur signals — narrowband interference, for instance, a CW carrier — to a 6 MHz-wide digital TV signal generally has two effects. If the interfering signal is strong enough, it will cause degraded *modulation error ratio* (MER) and degraded *bit error rate* (BER) in the digital video signal. If the amplitude of the interference is sufficient, the digital receiver's *forward error correction* (FEC) circuitry will be unable to fix the broken bits, and the digital video signal will "crash." (See the **Digital Modes** chapter for more information on coding and error correction in digital protocols.)

TV viewers watching any of the multiple video streams that may be contained within the digital video signal won't see any problems in the picture (or hear anything wrong in the sound), until the so-called "crash point" is reached. At that point, the picture will begin to show intermittent "tiling" (the picture breaking up into small squares) or blocking (freezing) in the image. As the amplitude of the interfering signal increases perhaps another 0.5 dB to 1 dB, the crash point or "digital cliff" is reached, and the picture and sound are gone! As you can see, there is a tiny window between receiving a perfect picture and receiving no picture. The same effect is

produced by signal fading and may be difficult to distinguish from RFI.

Interference to the digital signal does not make its presence known through visual or audible artifacts such as streaks, lines, or tearing in the picture, or garbled audio. This means that a viewer experiencing interference may not be able to identify its source, but troubleshooting interference may also become more difficult. Nevertheless, the more robust digital modulation is often less susceptible to interference from narrowband amateur signals. A clue to the source of the interference is that interference caused by an amateur signal will occur in sync with the amateur's transmissions while other types of interference will have no correlation.

The techniques for curing interference between amateur and digital TV signals are largely the same as for analog TV. Fundamental overload generally responds well to filters in the antenna or RF inputs. Interference caused by spurious emissions from the amateur station can be eliminated by filtering at the amateur transmitter. Common-mode problems in which RF signals are conducted into the television receiver's circuitry by external audio, video, and power cables are no more or less likely than for analog TV sets and can be addressed as described elsewhere in this chapter.

27.8.4 Cable TV

Cable TV has generally benefited Amateur Radio with respect to TVI. The cable system delivers a strong, consistent signal to the TV receiver, reducing susceptibility to interference from amateur signals. It is also a shielded system so an external signal shouldn't be able to cause interference. Most cable companies are responsible about keeping signal leakage (*egress*) and *ingress* — the opposite of leakage — under control, but problems do happen. Cable companies are not responsible for direct pickup or common-mode interference problems, but are responsible for leakage, ingress, and any noise radiated by common-mode currents from their equipment.

Cable companies are able to take advantage of something known as frequency reuse. That is, all radio frequencies higher than 5 MHz are used to transmit TV signals. The latter is possible because the cables and components used to transport signals to and from paying subscribers comprise what is known as a closed network. In other words, a cable company can use frequencies inside of its cables that may be used for entirely different purposes in the over-the-air environment. As long as the shielding integrity of the cable network is maintained, the cable company's signals won't interfere with over-the-air services, and vice-versa.

The reality is that the shielding integrity of a cable network *is* sometimes compromised, perhaps because of a loose or damaged connector, a cracked cable shield, rodent damage, poorly shielded customer premises equipment (CPE) such as cable-ready TVs and VCRs, and problems that may happen when someone tries to steal cable service! §76.605(a)(12) of the FCC Rules defines the maximum allowable signal leakage (*egress*) field strength at specified measurement distances, and §76.613 covers harmful interference. FCC Rules also mandate that cable operators "…shall provide for a program of regular monitoring for signal leakage by substantially covering the plant every three months," and leaks greater than 20 microvolts per meter (µV/m) at a 10 ft. measurement distance repaired in a reasonable period of time. As well, an annual "snapshot" of leakage performance must be characterized via a flyover measurement of the cable system, or a ground-based measurement of 75% of the network.

CABLE TV FREQUENCY USAGE

A typical modern North American cable network is designed to use frequencies in the 5 to 1002 MHz spectrum. Signals that travel from the cable company to the subscriber occupy frequencies from just above 50 MHz to as high as 1002 MHz range (this is the downstream or forward spectrum), and signals that travel from the subscriber to the cable company are carried in the 5 to as high as 42 MHz range, known as the upstream or return spectrum. The downstream is divided into 6 MHz-wide channel slots, which may carry analog NTSC television signals or 64- or 256-QAM digitally modulated signals used for digital video, high-speed data, and telephone services. Upstream signals from cable modems and two-way set-top boxes are generally carried on specific frequencies chosen by the cable company. **Table 27.2** summarizes cable downstream channel allocations that overlap Amateur Radio bands. The complete North American channel plan is shown in the TV Channel Chart on this book's CD-ROM.

Cable channels below about 550 MHz may carry analog NTSC signals or digital signals. Cable channels above 550 MHz generally carry digital signals, although there are exceptions. Cable channels above 870 MHz almost always carry only digital signals.

COMMON MECHANISMS FOR LEAKAGE AND INGRESS

As noted previously, cable TV leakage and ingress occur when the shielding integrity of the cable network is compromised. A large cable system that serves a major metropolitan area has literally millions of connectors, tens of thousands of miles of coaxial cable, thousands of amplifiers, hundreds of thousands of passives (splitters, directional couplers, and similar devices), and uncountable customer premises equipment connected to the cable network! Any of these may be a source of leakage and ingress.

DIGITAL SIGNAL LEAKAGE?

The digitally modulated signals carried in a cable TV network use 64-QAM or 256-QAM, the latter more common. (See the **Modulation** chapter for more information on Digital TV modulation.) If a QAM signal were to leak from a cable TV network, it is possible for interference to an over-the-air service to occur, but very unlikely to be identified as from a digital TV signal. The reason for this is that a QAM signal is noise-like, and sounds like normal background noise or hiss on a typical amateur receiver. The QAM signal's digital channel power — its average power over the entire occupied bandwidth — is typically 6 to 10 dB lower than what an analog TV signal's visual carrier peak envelope power

Table 27.2
Amateur Radio Bands Relative to Cable TV Downstream Channels

Amateur Band	*Over-The-Air Frequency Range*	*Cable Channel*	*Cable Frequency Range*
6 meters	50-54 MHz	Below Ch. 2	50-54 MHz, sometimes used for narrowband telemetry carriers
2 meters	144-148 MHz	Ch. 18	144-150 MHz
1.25 meters	222-225 MHz	Ch. 24	222-228 MHz
70 cm	420-450 MHz	Ch. 57	420-426 MHz
		Ch. 58	426-432 MHz
		Ch. 59	432-438 MHz
		Ch. 60	438-444 MHz
		Ch. 61	444-450 MHz
33 cm	902-928 MHz	Ch. 142	900-906 MHz
		Ch. 143	906-912 MHz
		Ch. 144	912-918 MHz
		Ch. 145	918-924 MHz
		Ch. 146	924-930 MHz

Table 27.3
VHF Midband Cable Channels

Cable Channel	*Visual Carrier Frequency, MHz (STD)*	*Visual Carrier Frequency, MHz (IRC)*	*Visual Carrier Frequency, MHz (HRC)*
98	109.2750	109.2750	108.0250*
99	115.2750	115.2750	114.0250*
14	121.2625	121.2625	120.0060
15	127.2625	127.2625	126.0063
16	133.2625	133.2625	132.0066
17	139.25	139.2625	138.0069
18	145.25	145.2625	144.0072
19	151.25	151.2625	150.0075
20	157.25	157.2625	156.0078
21	163.25	163.2625	162.0081
22	169.25	169.2625	168.0084

*Excluded from HRC channel set because of FCC frequency offset requirements

(PEP) would be on the same channel. As well, a QAM signal occupies most of the 6 MHz channel slot, and there are no carriers *per se* within that channel bandwidth. Note that over-the-air 8-VSB digital TV broadcast signals transmit a pilot carrier near the lower end of the digital "haystack," but the QAM format used by cable operators has no comparable pilot carrier.

What makes the likelihood of interference occurring (or not occurring) has in large part to do with the behavior of a receiver in the presence of broadband noise. While each downstream cable TV QAM signal occupies close to 6 MHz of RF bandwidth, the IF bandwidth of a typical amateur FM receiver might be approximately 20 kHz. Thus, the noise power in the receiver will be reduced by $10\log_{10}(6{,}000{,}000/20{,}000) = 24.77$ dB because of the receiver's much narrower IF bandwidth compared to the QAM signal's occupied bandwidth. In addition, there is the 6 to 10 dB reduction of the digital signal's average signal PEP.

Field tests during 2009 confirmed this behavior, finding that a leaking QAM signal would not budge the S meter of a Yaesu FT-736R at low to moderate field strength leaks, even when the receiver's antenna — a resonant half-wave dipole — was located just 10 feet from a calibrated leak. In contrast, a CW carrier that produced a 20 µV/m leak resulted in an S meter reading of S9 +15 dB, definitely harmful interference! When the CW carrier was replaced by a QAM signal whose digital channel power was equal to the CW carrier's PEP and which produced the same leakage field strength (the latter integrated over the full 6 MHz channel bandwidth), the S-meter read <S1. When the leakage field strength was increased to 100 µV/m, the CW carrier pegged the S meter at S9 +60 dB, while the QAM signal was S3 in FM mode and between S1 and S2 in USB mode. It wasn't until the leaking QAM signal's field strength reached several hundred µV/m that the "noise" (and it literally sounded like typical white noise) could be construed to be harmful interference.

ANALOG TV CHANNEL LEAKAGE SYMPTOMS

When signal leakage does happen, interference to the amateur service may occur. And where there is leakage, there is probably ingress. That compounds the problem, because not only are you experiencing interference, but when you transmit you may interfere with cable service in the area. One of the most common signs of possible leakage is interference to the 2 meter amateur band, especially in the vicinity of standard (STD) cable channel 18's visual carrier on 145.25 MHz. If you suspect cable leakage, listen for the telltale buzz from the video signal on or near 145.25 MHz (sometimes buzz may not be heard), and check other STD, incrementally related carrier (IRC), and harmonically related carrier (HRC) visual carrier frequencies on nearby channels listed in **Table 27.3** using a wide range receiver or scanner. (Leakage of a digital TV signal on cable channel 18 sounds like broadband noise over the 144-150 MHz range.) Also listen for TV channel sound on the FM aural carriers 4.5 MHz above the visual carriers.

LOCATING LEAKAGE SOURCES

When a cable company technician troubleshoots signal leakage, the process is similar to Amateur Radio fox hunting. The technician uses radio direction finding techniques that may include equipment such as handheld dipole or Yagi antennas, Doppler antenna arrays on vehicles, near-field probes, and commercially manufactured signal leakage detectors. Many leakage detectors incorporate what is known as "tagging" technology to differentiate a leaking cable signal from an over-the-air signal or electrical noise that may exist on or near the same frequency. Most leakage detection is done on a dedicated cable channel in the 108-138 MHz frequency range.

ELIMINATING LEAKAGE

A large percentage of leakage and ingress problems are not the result of a single shielding defect, although this does happen. For example, a squirrel might chew a hardline feeder cable, or a radial crack might develop in the shield as a consequence of environmental or mechanical damage. Most often, leakage and ingress are caused by several small shielding defects in an area: loose or corroded hardline connectors and splices, old copper braid subscriber drop cabling, improperly installed F connectors, subscriber-installed substandard "do-it-yourself" components, and the previously mentioned poorly shielded cable-ready TVs and other *customer premises equipment* (*CPE*).

After the cable technician locates the source(s) of the leakage, it is necessary to repair or replace the culprit components or cabling. In the case of poorly shielded TVs or VCRs, the cable technician cannot repair those devices, only recommend that they be fixed by a qualified service shop. Often the installation of a set-top box will take care of a cable-ready CPE problem because the subscriber drop cabling is no longer connected directly to the offending device. The latter usually resolves direct pickup problems, too, because the cable-ready TV must be tuned to channel 3 or 4 to receive the set-top signals.

VERIFYING AN RFI SOURCE TO BE LEAKAGE

Spurious signals, birdies, harmonics, intermodulation, electrical noise, and even interference from Part 15 devices are sometimes mistaken for cable signal leakage. One of the most common is emissions from Part 15 devices that become coupled to the cable TV coax shield in some way. Non-leakage noise or spurious signals may radiate from the cable TV lines or an amplifier location, but only because the outer surface of the cable shield is carrying the coupled interference as a common-mode current.

When interference from what sounds like a discrete carrier in the downstream spectrum is received, note the frequency and compare it to known analog TV channel visual and aural carrier frequencies. Consider the following example in which an interfering signal is being heard in the 70 cm amateur band and it falls within cable channel 60 (438-444 MHz). When a cable operator carries an analog TV channel that complies with the STD channel frequency plan (Table 27.3), the visual carrier is at 439.25 MHz. The aural carrier falls 4.5 MHz above the visual carrier, or 443.75 MHz. If the cable operator were using HRC channelization rather than STD

channelization, channel 60's visual carrier would be at 438.0219 MHz and its aural carrier at 442.5219 MHz. Can you hear anything at either visual carrier frequency? What about the aural carrier frequencies? Since the visual carrier is the strongest part of an analog TV channel, that's the best place to listen for leakage.

The color subcarrier of STD channel 60 falls at 439.25 + 3.58 = 442.83 MHz, but this is a double sideband suppressed carrier. There are horizontal sidebands spaced every 15.734 kHz from the visual carrier (and also from the color subcarrier), but these are generally very low level. Analog TV channel visual carriers use AM, and the aural carriers use FM. If the interference is from the aural carrier of an analog TV channel, you may be able to hear the channel's audio. If the interfering carrier does not fall on expected cable frequencies, it may not be leakage.

A common non-leakage interference that may radiate from a cable network is broadband electrical interference or other noise in the MF and lower end of the HF spectrum. A common misconception is that since cable companies carry digital signals on frequencies that overlap portions of the over-the-air spectrum below 30 MHz, any "noise" that radiates from the cable plant must be leaking digital signals. This type of interference is almost always power-line electrical interference or other noise that is coupled to the cable network's shield as a common-mode signal.

Upstream digital signals from cable modems, which have channel bandwidths of 1.6, 3.2 or 6.4 MHz, are typically transmitted in the roughly 20 to 40 MHz range, and are bursty in nature rather than continuous like downstream digital signals. Set-top box upstream telemetry carriers are narrowband frequency shift keying (FSK) or quadrature phase shift keying (QPSK) carriers usually in the approximately 8 to 11 MHz range. This type of interference may respond to common-mode chokes. Radiated non-leakage noise-like interference from the outside of the hardline coaxial cables that happens outdoors, affecting MF and/or HF reception in the neighborhood, cannot be fixed using chokes. The source of the interference must be identified and repaired. A little RFI detective work may be necessary. Refer to the various RFI troubleshooting sections of this chapter.

If normal leakage troubleshooting techniques do not clearly identify the source of the interference, sometimes the cable company may temporarily shut off its network in the affected neighborhood. If the interference remains after the cable network is turned off, it is not leakage, and the cable company is not responsible for that type of interference. If the interference disappears when the cable network is turned off, then it most likely is leakage or something related to the cable network. Turning off even a small portion of the cable network is a last resort and may not be practical because of the service disruption to subscribers. It may be easier for the cable company to temporarily shut off a suspect cable channel briefly. Here, too, if the interference remains after the channel is turned off, the interference is not leakage.

HOW TO REPORT LEAKAGE

If you suspect cable signal leakage is causing interference to your amateur station, *never attempt your own repairs to any part of the cable network, even the cabling in your own home*! Document what you have observed. For instance, note the frequency or frequencies involved, the nature of the interference, any changes to the interference with time of day, how long it has been occurring, and so forth. If you have fox-hunting skills and equipment, you might note the probable source(s) of the interference or at least the direction from which it appears to be originating.

Next, contact the cable company. You will most likely reach the cable company's customer service department, but ask to speak with the local cable system's Plant Manager (may also be called Chief Engineer, Director of Engineering, Chief Tech, VP of Engineering, or similar), and explain to him or her that you are experiencing what you believe to be signal leakage-related interference. If you cannot reach this individual, ask that a service ticket be created, and a technician familiar with leakage and ingress issues be dispatched. Share the information you have gathered about the interference. And as with all RFI issues, remember diplomacy!

In the vast majority of cases when cable leakage interference to Amateur Radio occurs, it is able to be taken care of by working with local cable system personnel. Every now and then for whatever reason, the affected ham is unable to get the interference resolved locally. Contact the ARRL for help in these cases.

27.8.5 DVD and Video Players

A DVD or similar video player usually contains a television tuner or has a TV channel output. It is also connected to an antenna or cable system and the ac line, so it is subject to all of the interference problems of a TV receiver. Start by proving that the video player is the susceptible device. Temporarily disconnect the device from the television or video monitor. If there is no interference to the TV, then the video player is the most likely culprit.

Next, find out how the interfering signal is getting into the video player. Temporarily disconnect the antenna or cable feed line from the video player. If the interference goes away, then the antenna line is involved. In this case, you can probably fix the problem with a common-mode choke or high-pass filter.

Fig 27.21 shows a bulletproof video player installation. If you have tried all of the cures shown and still have a problem, the player is probably subject to direct pickup. In this case, contact the manufacturer through the CEA.

Some analog-type VCRs are quite susceptible to RFI from HF signals. The video baseband signal extends from 30 Hz to 3.5 MHz, with color information centered around 3.5 MHz and the FM sound subcarrier at 4.5 MHz. The entire video baseband is frequency modulated onto the tape at frequencies up to 10 MHz. Direct pickup of strong signals by VCRs is a common problem and may not be easily solved, short of replacing the VCR with a better-shielded model.

27.8.6 Non-radio Devices

Interference to non-radio devices is not the fault of the transmitter. (A portion of the *FCC Interference Handbook,* 1990 Edition, is shown in **Fig 27.22**. Although the FCC no longer offers this *Handbook*, an electronic version is available on this book's CD-ROM, from the ARRL at **www.arrl.org/fcc-rfi-information** or search the ARRL website for "cib interference handbook".) In essence, the FCC views non-radio devices that pick up nearby radio signals as improperly functioning; contact the manufacturer and return the equipment. The FCC does not require that non-radio devices include RFI protection and they don't offer legal protection to users of these devices that are susceptible to interference.

TELEPHONES

Telephones have probably become the number one, non-TVI interference problem of Amateur Radio. However, most cases of telephone interference can be cured by correcting any installation defects and installing telephone RFI filters where needed.

Telephones can improperly function as radio receivers. Semiconductor devices inside many telephones act like diodes. When such a telephone is connected to the telephone wiring (a large antenna) an AM radio receiver can be formed. When a nearby transmitter goes on the air, these telephones can be affected.

Troubleshooting techniques were discussed earlier in the chapter. The suggestion to simplify the problem applies especially to telephone interference. Disconnect all telephones except one, right at the service entrance if possible, and start troubleshooting the problem there.

If any single device or bad connection in the phone system detects RF and puts the detected signal back onto the phone line as audio, that audio cannot be removed with filters. Once the RF has been detected and turned into audio, it

PART II

INTERFERENCE TO OTHER EQUIPMENT

CHAPTER 6

TELEPHONES, ELECTRONIC ORGANS, AM/FM RADIOS, STEREO AND HI-FI EQUIPMENT

Telephones, stereos, computers, electronic organs and home intercom devices can receive interference from nearby radio transmitters. When this happens, the device improperly functions as a radio receiver. Proper shielding or filtering can eliminate such interference. The device receiving interference should be modified in your home while it is being affected by interference. This will enable the service technician to determine where the interfering signal is entering your device.

The device's response will vary according to the interference source. If, for example, your equipment is picking up the signal of a nearby two-way radio transmitter, you likely will hear the radio operator's voice. Electrical interference can cause sizzling, popping or humming sounds.

Fig 27.22 — Part of page 18 from the FCC *Interference Handbook* (1990 edition) explains the facts and places responsibility for interference to non-radio equipment.

cannot be filtered out because the interference is at the same frequency as the desired audio signal. To effect a cure, you must locate the detection point and correct the problem there.

Defective telephone company lightning arrestors can act like diodes, rectifying any nearby RF energy. Telephone-line amplifiers or other electronic equipment may also be at fault. Do not attempt to diagnose or repair any telephone company wiring or devices on the "telco" side of your service box or that were installed by the phone company. Request a service call from your phone company.

Inspect the telephone system installation. Years of exposure in damp basements, walls or crawl spaces may have caused deterioration. Be suspicious of anything that is corroded or discolored. In many cases, homeowners have installed their own telephone wiring, often using substandard wiring. If you find sections of telephone wiring made from nonstandard cable, replace it with standard twisted-pair telephone or CAT5 cable. If you do use telephone cable, be sure it is high-quality twisted-pair to minimize differential-mode pickup of RF signals.

Next, evaluate each of the telephone instruments. If you find a susceptible telephone, install a telephone RFI filter on that telephone, such as those sold by K-Y Filters. (**www.ky-filters.com**) If the home uses a DSL broadband data service, be sure that the filters do not affect DSL performance by testing online data rates with and without a filter installed at the telephone instrument.

If you determine that you have interference only when you operate on one particular ham band, the telephone wiring is probably resonant on that band. Install common-mode chokes on the wiring to add a high impedance in series with the "antenna." A telephone RFI filter may also be needed. (See the section on DSL Equipment for filtering suggestions.)

Telephone Accessories — Answering machines and fax machines are also prone to interference problems. All of the troubleshooting techniques and cures that apply to telephones also apply to these telephone devices. In addition, many of these devices connect to the ac mains. Try a common-mode choke and/or ac-line filter on the power cord (which may be an ac cord set, a small transformer or power supply).

Cordless Telephones — A cordless telephone is an unlicensed *radio* device that is manufactured and used under Part 15 of the FCC regulations. The FCC does not intend Part 15 devices to be protected from interference. These devices usually have receivers with very wide front-end filters, which make them very susceptible to interference.

A likely path for interference to cordless phones is as common-mode current on the base unit's connecting cables that will respond to common-mode chokes. In addition, a telephone filter on the base unit and an ac line filter may help. The best source of help is the manufacturer but they may point out that the Part 15 device is not protected from interference.

Cordless phone systems operating at 900 MHz and higher frequencies are often less susceptible to interference than older models that use 49 MHz. It may be easiest to simply replace the system with a model less susceptible to interference.

AUDIO EQUIPMENT

Consumer and commercial audio equipment such as stereos, home entertainment systems, intercoms and public-address systems can also pick up and detect strong nearby transmitters. The FCC considers these non-radio devices and does not protect them from licensed radio transmitters that may interfere with their operation. The RFI can be caused by one of several things: pickup on speaker leads or interconnecting cables, pickup by the ac mains wiring or direct pickup. If the

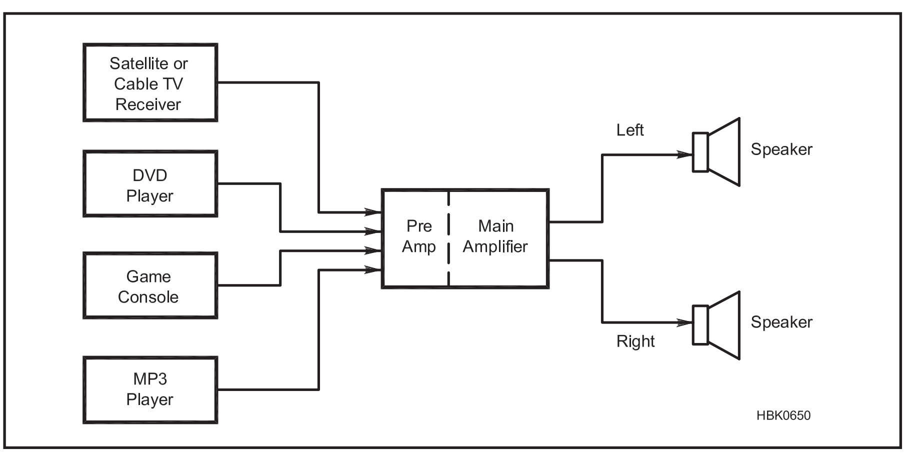


Fig 27.23 — A typical modern home-entertainment system.

interference involves wiring connected to the affected device, common-mode chokes are the most likely solution.

Use the standard troubleshooting techniques discussed earlier in this chapter to isolate problems. In a multi-component home entertainment system (as in **Fig 27.23**), for example, you must determine what combination of components is involved with the problem. First, disconnect all auxiliary components to determine if there is a problem with the main receiver/amplifier. Long speaker or interconnect cables are prime suspects.

Stereos and Home Entertainment Systems — If the problem remains with the main amplifier isolated, determine if the interference level is affected by the volume control. If so, the interference is getting into the circuit *before* the volume control, usually through accessory wiring. If the volume control has no effect on the level of the interfering sound, the interference is getting in *after* the control, usually through speaker wires.

Speaker wires are often effective antennas on HF and sometimes into VHF and above. The speaker terminals are often connected directly to the output amplifier transistors. Modern amplifier designs use a negative feedback loop to improve fidelity. This loop can conduct the detected RF signal back to the high-gain stages of the amplifier. The combination of all of these factors often makes the speaker cables the dominant receiving antenna for RFI.

There is a simple test that will help determine if the interfering signal is being coupled into the amplifier by the speaker leads. Temporarily disconnect the speaker leads from the amplifier, and plug in a test set of headphones with short leads. If there is no interference with the headphones, filtering the speaker leads will likely cure the problem.

Start by applying common-mode chokes. **Fig 27.24** shows how to wrap speaker wires around an large (2-inch O.D. or larger) ferrite core to cure speaker-lead RFI. Type 31 material is preferred at HF. (See the section on Common-Mode Chokes in this chapter.)

In some cases, the speaker wires may be picking up RF as a differential-mode signal. To reduce differential-mode pickup, replace the zip cord speaker wire with twisted-pair wire. (#16 AWG will work for most systems with higher-power systems requiring #12 AWG.)

Powered Speakers — A powered speaker is one that has its own built-in power amplifier. Powered subwoofers are common in home entertainment systems and small powered speakers are often used with computer and gaming systems. If a speaker runs on batteries and/or an external power supply, or is plugged into mains power, it is a powered loudspeaker. Powered loudspeakers are notoriously susceptibility to common-mode interference from internally misconnected cable shields and poor shielding. Apply suitable common-mode chokes to all wiring, including power wiring. If the RFI persists, try an RF filter at the input to the speaker, such as the LC low-pass filter in **Fig 27.25**. Unshielded speakers may not be curable, however.

Intercoms and Public-Address Systems — RFI to these systems is nearly always caused by common-mode current on interconnect wiring. Common-mode chokes are the most likely cure, but you may also need to contact the manufacturer to see if they have any additional, specific information. Wiring can often be complex, so any work on these systems should be done by a qualified sound contractor.

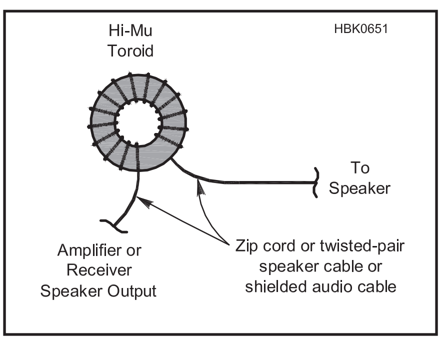


Fig 27.24 — Making a speaker-lead common-mode choke. Use ferrite material appropriate for the frequency of the RF interference.

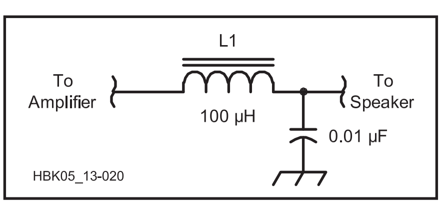


Fig 27.25 — A low-pass LC filter.

COMPUTERS AND OTHER UNLICENSED RF SOURCES

Computers and microprocessor-based devices such as video games or audio players can be sources or victims of interference. These devices contain oscillators that can and do radiate RF energy. In addition, the internal functions of a computer generate different frequencies, based on the various data signals. All of these signals are digital — with fast rise and fall times that are rich in harmonics.

Computing devices are covered under Part 15 of the FCC regulations as unintentional emitters. As for any other unintentional emitter, the FCC has set absolute radiation limits for these devices. As previously discussed in this chapter, FCC regulations state that the operator or owner of Part 15 devices must take whatever steps are necessary to reduce or eliminate any interference they cause to a licensed radio service. This means that if your neighbor's video game interferes with your radio, the neighbor is responsible for correcting the problem. (Of course, your neighbor may appreciate your help in locating a solution!)

The FCC has set up two tiers of limits for computing devices. Class A is for computers used in a commercial environment. FCC Class B requirements are more stringent — for computers used in residential environments. If you buy a computer or peripheral, be sure that it is Class B certified or it will probably generate interference to your amateur station or home-electronics equipment.

If you find that your computer system is interfering with your radio (not uncommon in this digital-radio age), start by simplifying the problem. Temporarily remove power from as many peripheral devices as possible and disconnect their cables from the back of the computer. (It is necessary to physically remove the power cable from the device, since many devices remain in a low-power state when turned off from the front panel or by a software command.) If possible, use just the computer, keyboard and monitor. This test may identify specific peripherals as the source of the interference.

Ensure that all peripheral connecting cables are shielded. Replace any unshielded cables with shielded ones; this often significantly reduces RF noise from computer systems. The second line of defense is the common-mode choke. The choke should be installed as close to the computer and/or peripheral device as practical. **Fig 27.26** shows the location of common-mode chokes in a complete computer system where both the computer and peripherals are noisy.

Switchmode power supplies in computers are often sources of interference. A common-mode choke and/or ac-line filter may cure this problem. In extreme cases of computer interference you may need to improve the shielding of the computer. (Refer to the *ARRL RFI Book* for more information about this.) Don't forget that some peripherals (such as modems) are connected to the phone line, so you may need to treat them like telephones.

GROUND-FAULT AND ARC-FAULT CIRCUIT INTERRUPTORS (GFCI AND AFCI)

GFCIs are occasionally reported to "trip" (open the circuit) when a strong RF signal, such as an amateur's HF transmission, is present. GFCI circuit breakers operate by sensing unbalanced currents in the hot and neutral conductors of an ac circuit. In the absence of RF interference, such an imbalance indicates the presence of a fault somewhere in the circuit, creating a shock hazard. The breaker

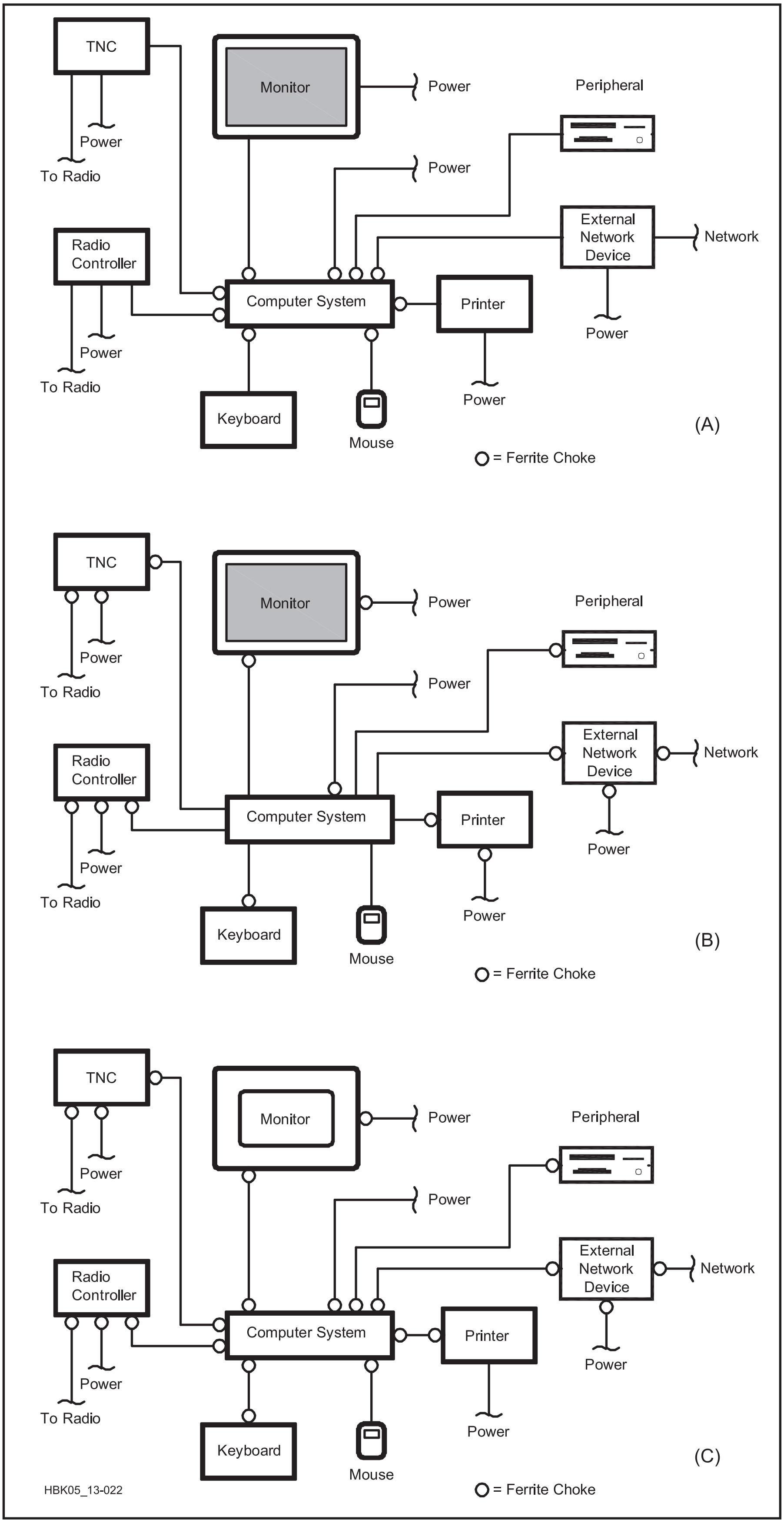


Fig 27.26 — Where to locate ferrite chokes in a computer system. At A, the computer is noisy, but the peripherals are quiet. At B, the computer is quiet, but external devices are noisy. At C, both the computer and externals are noisy.

then trips (opens) to remove the shock hazard.

An Arc Fault Circuit Interrupter (AFCI) circuit breaker is similar in that it monitors current to watch for a fault condition. Instead of current imbalances, the AFCI detects patterns of current that indicate an arc — one of the leading causes of home fires. The AFCI is not supposed to trip because of "normal" arcs that occur when a switch is opened or a plug is removed.

Under current codes, GFCI protection is required for all basement outlets, outdoor outlets, and for outlets in kitchens and bathrooms. AFCI protection is required for all circuits that supply bedrooms.

RF interference to GFCI breakers is caused by RF current or voltage upsetting normal operation of the imbalance detection circuit, resulting in the false detection of a fault. Similarly, RF current or voltage could upset the arc detection circuitry of an AFCI breaker. Some early GFCI breakers were susceptible to RFI, but as the technology has improved, fewer and fewer such reports have been received. While it is possible to add filtering or RF suppression to the breaker wiring, a simpler and less expensive solution is to replace the GFCI breaker with a new unit less susceptible to RF.

The ARRL Lab has received favorable reports on the following GFCI products:

- Leviton (**www.leviton.com**) GFCI outlets which are available in both 15 and 20 A versions for 120 V ac circuits as well as cord sets and user-attachable plugs and receptacles.
- Bryant (**www.bryant-electric.com**) ground fault receptacles which feature published 0.5 V immunity from 150 kHz to 230 MHz.
- Cooper (**www.cooperindustries.com**) GFCI products that are labeled "UL 943 compliant" on the package.

A web page on the ARRL website is maintained on GFCI/AFCI technology (**www.arrl.org/gfci-devices**). Reports have not been received on AFCI products as of early 2013. Since AFCI technology is newer than GFCI, immunity to RF may be less of a problem than with the initial GFCI products.

WALL TRANSFORMER SWITCHING SUPPLIES

While small, low-current linear power supplies known as "wall warts" have been widely used for many years, it is now becoming common for these devices to contain switchmode or "switcher" supplies. Because they must be manufactured very inexpensively, these supplies often have little or no RF filtering at either the ac input or dc output, frequently creating significant RFI to nearby amateurs.

The least expensive course of action may be to simply replace the switchmode supply with a linear model. If the system in which

the supply is used is still under warranty, the distributor or manufacturer may be able to replace it. Otherwise, a third-party linear replacement may be available with the same voltage rating and current output equal to or higher than the original supply. Adapters may be available to convert output connector styles where necessary or new connectors installed.

If replacing the supply with a linear model is not an option, you will have to apply RF filters to the supply. These supplies are rarely serviceable, so filters much be installed externally. Noise is usually radiated from the output cable so winding the cable onto a ferrite core creates a common-mode RF choke as described in this chapter's Elements of RFI Control section. Since the wall-wart style supply plugs directly into a wall-mounted receptacle, an ac filter must either be installed in the ac outlet box or a short ac extension cord can be made into a common-mode choke, as well.

27.9 Automotive RFI

Automobiles have evolved from a limited number of primitive electrical components to high technology, multi-computer systems on-wheels. Every new technology deployed can potentially interfere with amateur equipment.

Successful mobile operation depends on a multitude of factors such as choosing the right vehicle, following installation guidelines, troubleshooting and deploying the appropriate RFI fixes as needed.

A number of these factors will be covered in this section. Additionally, newly emerging electrical and hybrid-electric vehicles will be discussed, which pose unique challenges to amateur equipment installations and operation.

27.9.1 Before Purchasing a Vehicle

When shopping for a new vehicle intended for a mobile amateur installation, begin with research. A wealth of information is available on the Internet, and specifically at **www.arrl.org/automotive**, where the ARRL has compiled years of data from automotive manufacturers and other hams. Email reflectors and websites may provide information from hams willing to share their experiences concerning mobile communications in their own vehicles that may be the very make and model you were considering.

Armed with research, your next stop is your dealer. The manufacturer of each vehicle is the expert on how that vehicle will perform. The dealer should have good communication with the manufacturer and should be able to answer your questions. Ask about service bulletins and installation guidelines. You can also ask your dealer about fleet models of their vehicles. Some manufacturers offer special modifications for vehicles intended for sale to police, taxicabs and other users who will be installing radios (usually operating at VHF and UHF) in their cars.

When shopping for a vehicle, it is useful to take along some portable (preferably battery operated) receivers or scanners and have a friend tune through your intended operating frequencies while you drive the vehicle. This will help identify any radiated noise issues associated with that model vehicle, which can be more difficult to resolve than conducted noise. If you intend to make a permanent transceiver installation, give some consideration to how you will mount the transceiver and route the power and/or antenna cables. While looking for ways to route the wiring, keep in mind that some newer cars have the battery located in the trunk or under the rear seat, and that may make power wire routing easier.

Test the car before you buy it. A dealer expects you to take the car for a test ride; a cooperative dealer may let you test it for radio operation, too. A fair amount of checking can easily be performed without digging too deeply into the car. Check the vehicle for noise with a portable receiver on VHF, where your handheld transceiver will do the job nicely. On HF, you can usually locate noise with a portable short-wave receiver, or operate your HF transceiver with a portable antenna and cigarette-lighter plug. With the engine running, tune across the bands of interest. You may hear some noise, or a few birdies, but if the birdies don't fall on your favorite frequency, this is an encouraging sign! Check with the vehicle completely off, with the key in the ignition, and with the vehicle running — electronic subsystems operate in different ways with the vehicle running or not running.

To test the vehicle for susceptibility to your transmitted signal, you must transmit. It is important to note that without a full and complete installation, you will not be able to fully assess the effects of full-power transmissions on a vehicle. Any testing done with temporary equipment installations cannot be considered an absolute guarantee because an installed transmitter connected directly to the vehicle's power source may cause the vehicle to act differently.

To perform transmit tests, bring your radio and a separate battery (if permitted by dealer) so you can transmit at full power while in motion without having to run cables to the vehicle battery. Use a magnet-mount antenna (several *QST* advertisers sell mounts suitable for HF) for temporary testing. (Use the magnet-mount carefully; it is possible to scratch paint if any particles of dirt get on the bottom of the magnets.) Transmit on each band you will use to see if the RF has any effect on the vehicle. Lack of response to your transmissions is a good sign, but does not mean the vehicle is immune to RF as a permanent installation will result in different (likely stronger) field strengths and distributions in and around the vehicle and a permanent antenna more effectively coupled to the vehicle.

On both transmit and receive, you may want to experiment with the placement of the antenna. Antenna placement plays an important role in operation, and you may be able to find an optimal location for the antenna that predicts good performance with a permanent installation.

27.9.2 Transceiver Installation Guidelines

While most amateurs are familiar with the process of installing a transceiver, there are preferred practices that will help minimize potential problems. These include support from the automotive dealer, typical "best practices" installations, and consideration of special situations.

The first step is to ensure that your installation complies with both the vehicle manufacturer's and radio transceiver manufacturer's installation guidelines. Links to domestic automotive manufacturer installation guidelines are found at **www.arrl.org/automotive**. Automotive manufacturers that import vehicles for sale here do not publish installation guidelines because their vehicles are not typically used in police, fire and taxicab applications within the US.

The installation guidelines of different manufacturers vary as to how to install a radio transceiver's power leads. Most manufactur-

ers recommend that the positive and negative leads from the radio be run directly to the battery. This minimizes the potential for the interaction between the radio's negative lead currents and vehicle electronics. If the manufacturer recommends that both wires be connected to the battery, they will also require that both wires be fused. This is necessary because, in the unlikely event that the connection between the battery and the engine block were to fail, excessive current could be drawn on the radio's negative lead when the vehicle starter is engaged.

Some vehicles provide a "ground block" near the battery for a negative cable to be connected. On these vehicles, run the negative power lead, un-fused, to the "ground block." When this technique is recom-mended by the manufacturer, the interaction between the power return currents and vehicle electronics has been evaluated by the manufacturer. In all cases, the most important rule to remember is this: If you want the manufacturer to support your installation, do it exactly the way the installation guidelines tell you to do it!

If no installation guidelines are available for your vehicle, the practices outlined below will improve compatibility between in-vehicle transceivers and vehicle electronics:

1) Transceivers

- Transceivers should be mounted in a location that does not interfere with vehicle operator controls and visibility, provides transceiver ventilation, and be securely mounted.
- Ensure all equipment and accessories are removed from the deployment path of the airbag and safety harness systems.

2) Power Leads

- The power leads should be twisted together from the back of the rig all the way to the battery. This minimizes the area formed by the power leads, reducing susceptibility to transients and RFI.
- Do not use the vehicle chassis as a power return.
- The power leads should be routed along the body structure, away from vehicle wiring harnesses and electronics.
- Any wires connected to the battery should be fused at the battery using fuses appropriate for the required current.
- Use pass-through grommets when routing wiring between passenger and engine compartments.
- Route and secure all under hood wiring away from mechanical hazards.

3) Coaxial Feed Lines

- The coaxial feed line should have at least 95% braid coverage. The cable shield should be connected to every coaxial connector for the entire circumference (no "pigtails").
- Keep antenna feed lines as short as practical and avoid routing the cables parallel to vehicle wiring.

4) Antennas

- Antenna(s) should be mounted as far from the engine and the vehicle electronics as practical. Typical locations would be the rear deck lid or roof. Metal tape can be used to provide an antenna ground plane on non-metallic body panels.
- Care should be used in mounting antennas with magnetic bases, since magnets may affect the accuracy or operation of the compass in vehicles, if equipped.
- Since the small magnet surface results in low coupling to the vehicle at HF, it is likely that the feed line shield will carry substantial RF currents. A large (2-inch OD or larger toroid) common-mode choke at the antenna will help reduce this current, but will also reduce any radiation produced by that current.
- Adjust the antenna for a low SWR.

27.9.3 Diagnosing Automotive RFI

Most VHF/UHF radio installations should result in no problems to either the vehicle systems or the transceiver, while HF installations are more likely to experience problems. In those situations where issues do occur, the vast majority are interference to the receiver from vehicle on-board sources of energy that are creating emissions within the frequency bands used by the receiver. Interference to one of the on-board electronic systems can be trivial or it can cause major problems with an engine control system.

The dealer should be the first point of contact when a problem surfaces, because the dealer should have access to information and factory help that may solve your problem. The manufacturer may have already found a fix for your problem and may be able to save your mechanic a lot of time (saving you money in the process). If the process works properly, the dealer/customer-service network can be helpful. In the event the dealer is unable to solve your problem, the next section includes general troubleshooting techniques you can perform independently.

GENERAL TROUBLESHOOTING TECHNIQUES

An important aspect is to use the source-path-victim model presented earlier in this chapter. The path from the source to the receiver may be via radiation or conduction. If the path is radiation, the electric field strength (in V/m) received is reduced as a function of the distance from the source to the receiver. In most cases, susceptible vehicle electronics is in the near-field region of the radiating source, where the electric and magnetic fields can behave in complex ways. In general, however, the strength of radiated signals falls off with distance.

The best part of all this is that with a general-coverage receiver or spectrum analyzer, a fuse puller and a shop manual, the vehicle component needing attention may be identified using a few basic techniques. The only equipment needed could be as simple as:

- A mobile rig, scanner or handheld transceiver, or
- Any other receiver with good stability and an accurate readout, and
- An oscilloscope for viewing interference waveforms

BROADBAND NOISE

Automotive broadband noise sources include:

- Electric motors such as those that operate fans, windows, sunroof, AM/FM antenna deployment, fuel pumps, etc.
- Ignition spark

If you suspect electric motor noise is the cause of the problem, obtain a portable AM or SSB receiver to check for this condition. Switch on the receiver and then activate the electric motors one at a time. When a noisy motor is switched on, the background noise increases. It may be necessary to rotate the radio, since portable AM radios use a directional ferrite rod antenna.

To check whether fuel pumps, cooling fans, and other vehicle-controlled motors are the source of noise, pull the appropriate fuse and see whether the noise disappears.

A note concerning fuel pumps: virtually every vehicle made since the 1980s has an electric fuel pump, powered by long wires. It may be located inside the fuel tank. Don't overlook this motor as a source of interference just because it may not be visible. Electric fuel-pump noise often exhibits a characteristic time pattern. When the vehicle ignition switch is first turned on, without engaging the starter, the fuel pump will run for a few seconds, and then shut off when the fuel system is pressurized. At idle, the noise will generally follow the pattern of being present for a few seconds before stopping, although in some vehicles the fuel pump will run almost continuously if the engine is running.

NARROWBAND NOISE

Automotive narrowband noise sources include:

- Microprocessor based engine control systems
- Instrument panel
- RADAR obstacle detection
- Remote keyless entry
- Key fob recognition systems
- Tire pressure monitoring systems
- Global positioning systems
- Pulse width modulating motor speed controls
- Fuel injectors
- Specialized electric traction systems found in newer hybrid/electric vehicles

Start by moving the antenna to different

locations. Antenna placement is often key to resolving narrowband RFI problems. However, if antenna location is not the solution, consider pulling fuses. Tune in and stabilize the noise, then find the vehicle fuse panels and pull one fuse at a time until the noise disappears. If more than one module is fed by one fuse, locate each module and unplug it separately. Some modules may have a "keep-alive" memory that is not disabled by pulling the fuse. These modules may need to be unplugged to determine whether they are the noise source. Consult the shop manual for fuse location, module location, and any information concerning special procedures for disconnecting power.

A listening test may verify alternator noise, but if an oscilloscope is available, monitor the power line feeding the affected radio. Alternator whine appears as full-wave rectified ac ripple and rectifier switching transients superimposed on the power system's dc power voltage (see **Fig 27.27**).

Alternators rely on the low impedance of the battery for filtering. Check the wiring from the alternator output to the battery for corroded contacts and loose connectors when alternator noise is a problem.

Receivers may allow conducted harness noise to enter the RF, IF or audio sections (usually through the power leads), and interfere with desired signals. Check whether the interference is still present with the receiver powered from a battery or power supply instead of from the vehicle. If the interference is no longer present when the receiver is operating from a battery or external supply, the interference is conducted via the radio power lead. Power line filters installed at the radio may resolve this problem.

27.9.4 Eliminating Automotive RFI

The next section includes various techniques to resolve the more common RFI problems. As a caveat, performing your own RFI work, in or out of warranty, you assume the same risks as you do when you perform any other type of automotive repair. Most state laws (and common sense) say that those who work on cars should be qualified to do so. In most cases, this means that work should be done either by a licensed dealer or automotive repair facility.

CONDUCTED INTERFERENCE

To reduce common-mode current, impedance can be inserted in series with the wiring in the form of common-mode chokes. (See this chapter's section on Common-Mode Chokes.) Wire bundles may also be wound around large toroids for the same effect.

Mechanical considerations are important in mobile installations. A motor vehicle is subject to a lot of vibration. If a choke is installed on a wire, this vibration may cause the choke to flex the wire, which may ultimately fail. It is critical that any additional shielding and/or chokes placed on wiring have been installed by qualified personnel who have considered these factors. These must be properly secured, and sometimes cable extenders are required to implement this fix.

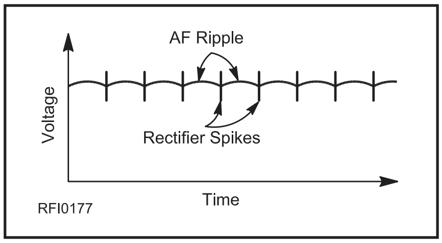


Fig 27.27 — Alternator whine consists of full-wave rectified ac, along with pulses from rectifier switching, superimposed on the vehicle's dc power voltage.

RFI TO ON-BOARD CONTROL SYSTEMS

RFI to a vehicle's on-board control and electronic modules should be treated with common-mode chokes at the connection to the module. Some success has been reported by using braid or metal foil to cover a wire bundle as a shield and connecting the shield to the vehicle chassis near the affected module. Vehicle electronic units should not be modified except by trained service personnel according to the manufacturer's recommendations. The manufacturer may also have specific information available in the form of service bulletins.

FILTERS FOR DC MOTORS

If the motor is a conventional brush- or commutator-type dc motor, the following cures shown in **Fig 27.28** are those generally used. As always, the mechanic should consult with the vehicle manufacturer. To diagnose motor noise, obtain an AM or SSB receiver to check the frequency or band of interest. Switch on the receiver, and then activate the electric motors one at a time. When a noisy motor is switched on, the background noise increases as well.

The pulses of current drawn by a brush-commutator motor generate broadband RFI that is similar to ignition noise. However, the receiver audio sounds more like bacon frying rather than popping. With an oscilloscope displaying receiver audio, the noise appears as a series of pulses with random space between the pulses. Such broadband noise generally has a more pronounced effect on AM receivers than on FM. Unfortunately, the pulses may affect FM receivers by increasing the "background noise level" and will reduce perceived receiver sensitivity because of the degraded signal-to-noise ratio.

ALTERNATOR AND GENERATOR NOISE

As mentioned previously, brush-type motors employ sliding contacts which can generate noise. The resulting spark is primarily responsible for the "hash" noise associated with these devices. Hash noise appears as overlapping pulses on an oscilloscope connected to the receiver audio output. An alternator also has brushes, but they do not interrupt current. They ride on slip rings and supply a modest current, typically 4 A to the field winding. Hence, the hash noise produced by alternators is relatively minimal.

Generators use a relay regulator to control field current and thus output voltage. The voltage regulator's continuous sparking creates broadband noise pulses that do not overlap in time. They are rarely found in modern automobiles.

Alternator or generator noise may be conducted through the vehicle wiring to the power

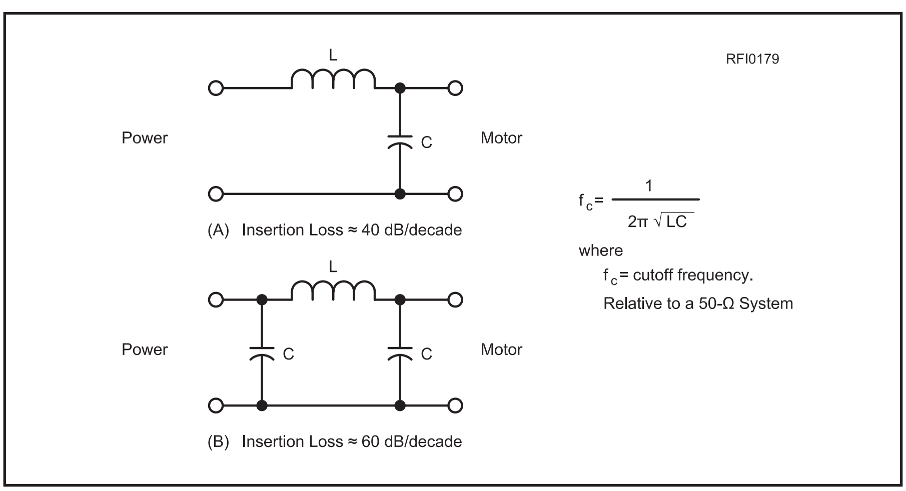


Fig 27.28 — Filters for reducing noise from dc motors

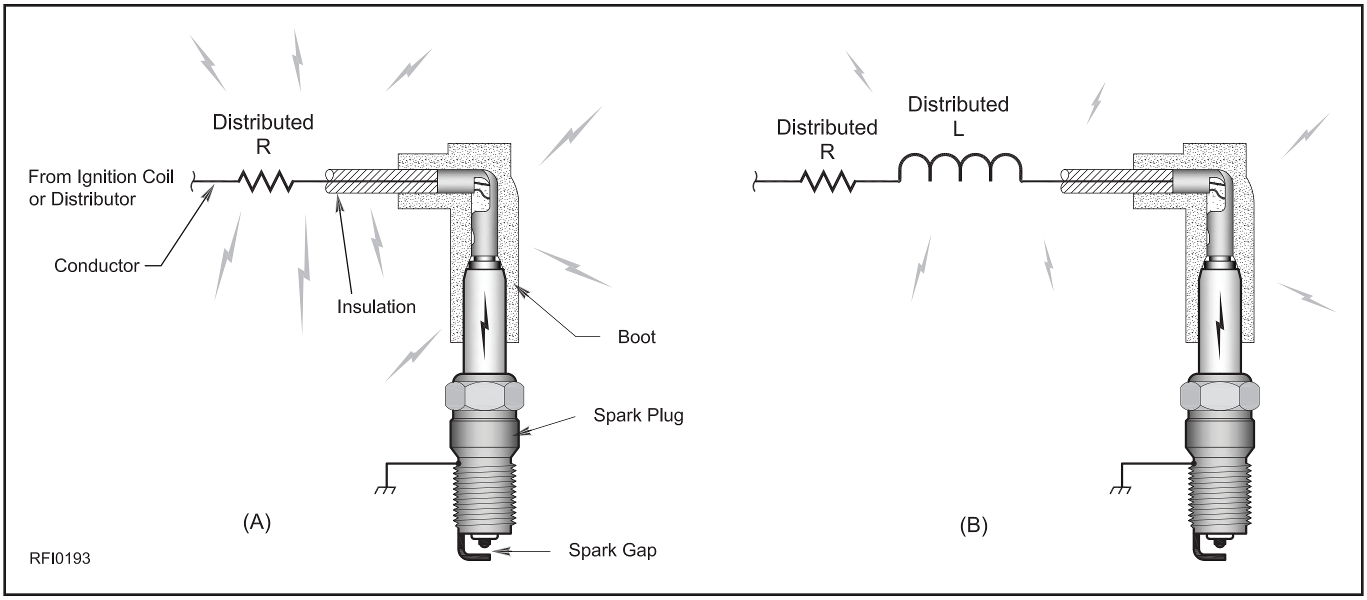


Fig 27.29 — Ignition noise suppression methods.

input of mobile receivers and transmitters and may then be heard in the audio output. If alternator or generator noise is suspected and an oscilloscope is not available, temporarily remove the alternator belt as a test. (This may not be possible in vehicles with a serpentine belt.)

IGNITION NOISE

Ignition noise is created by fast-rise-time pulses of coil current discharging across air gaps (distributor and spark plug). The theoretical models (zero rise time) of such pulses are called impulse functions in the time domain. When viewed in the frequency domain, the yield is a constant spectral energy level starting nearly at 0 Hz and theoretically extending up in frequency to infinity. In practice, real ignition pulses have a finite rise time, so the spectral-energy envelope decreases above some frequency.

It turns out that noise generated by ignition sparks and fuel injector activation manifest themselves as a regular, periodic "ticking" in the receiver audio output, which varies with engine RPM. If an oscilloscope were connected to the audio output, a series of distinct, separate pulses would appear. At higher speeds it sounds somewhat musical, like alternator whine, but with a harsher note (more harmonic content).

A distinguishing feature of ignition noise is that it increases in amplitude under acceleration. This results from the increase in the required firing voltage with higher cylinder pressure. (Noise at higher frequencies may also be reproduced better by the audio circuits.) Since ignition noise is usually radiated noise, it should disappear when the antenna element is disconnected from the antenna mount. The radiation may be from either the secondary parts of the system or it may couple from the secondary to the primary of the coil and be conducted for some distance along the primary wiring to the ignition system, then radiated from the primary wiring.

Two main methods are employed to suppress this noise — one involves adding an inductance, and the other involves adding a resistance — both in the secondary (high voltage) wiring. This is shown in **Fig 27.29**. The addition of these elements does not have a measurable effect on the engine operation, because the time constants involved in the combustion process are much longer than those associated with the suppression components. (Note that modifying your vehicle's ignition system may be considered as tampering with your vehicle's emission control system and may affect your warranty coverage — work with your dealer or limit your efforts to changing spark plug wires or possibly shielding them.)

The resistance method suppresses RFI by dissipating energy that would have been radiated and/or conducted. Even though the amount of energy dissipated is small, it is still enough to cause interference to sensitive amateur installations. The other method uses inductance and even though the energy is not dissipated, suppression occurs because the inductor will store the pulse energy for a short time. It then releases it into the ignition burn event, which is a low impedance path, reducing the RFI.

For traditional "Kettering" inductive discharge ignition systems, a value of about 5 kΩ impedance (either real and/or reactive) in the spark plug circuit provides effective suppression and, with this value, there is no detectable engine operation degradation. (Capacitor discharge systems, in comparison, are required to have very low impedance on the order of tens of ohms in order to not reduce spark energy, so they are not tolerant of series impedance). Most spark plug resistances are designed to operate with several kV across the plug gap, so a low-voltage ohmmeter may not give proper resistance measurement results.

The term "resistor wire" is somewhat misleading. High-voltage ignition wires usually contain both resistance and inductance. The resistance is usually built into suppressor spark plugs and wires, while there is some inductance and resistance in wires, rotors and connectors. The elements can be either distributed or lumped, depending on the brand, and each technique has its own merit. A side benefit of resistance in the spark plug is reduced electrode wear.

COIL-ON-PLUG IGNITION NOISE

Many newer spark-ignition systems incorporate a "coil on plug" (COP) or "coil near plug" (CNP) approach. There are advantages to this from an engine operation standpoint, and this approach may actually reduce some of the traditional sources of ignition system RFI. This is because of the very short secondary wires that are employed (or perhaps there are no wires — the coil is directly attached to the spark plug). This reduces the likelihood of coupling from the secondary circuit to other wires or vehicle/engine conductive structures.

There will always be some amount of energy from the spark event that will be conducted along the lowest impedance path. It may mean that the energy that would have been in the secondary circuit will be coupled back on the primary wiring harness attached

to the coils. This means that the problem may go from a radiated to a conducted phenomenon.

The fix for this in some cases may actually be easier or harder than one might think. Two approaches that have been used with success are ferrite cores and bypass capacitors.

Ferrite cores are recommended as the first choice, since they require no electrical modification to the vehicle. Ferrite clamp-on split cores are added to the 12-V primary harness attached to the coils. Depending on the frequency of the noise and selection of the ferrite material, there can be significant improvement (as much as 10 dB). Key to optimizing the amount of suppression is to determine where the noise "peaks" and selecting the correct ferrite material for that frequency range (see this chapter's section Using Ferrite for RFI Suppression).

The second method is to add a bypass capacitor between the primary wire of the 12-V coil and ground in the harness near the coil assemblies (there may be 2, 3 or 4 coils). This must be done carefully because it could affect the functionality of the ignition system and — perhaps most importantly — may void the vehicle warranty. This "bypass" capacitor performs the same function that bypass capacitors in any other application perform — separating the noise from the intended signal/power.

27.9.5 Electric and Hybrid-Electric Vehicles

Electric vehicles (EV) and hybrid-electric vehicles (HEV) are quickly becoming a practical means of transportation. EV/HEVs are advanced vehicles that pose unique challenges for amateur equipment. While EV/HEVs provide improved emissions and fuel economy, EV/HEVs utilize switched high voltage and high current to control propulsion. The switching techniques used generate RFI within much of our frequency bands — a cause for concern, particularly for HF operation.

This section is designed to enlighten vehicle owners to the challenges and to make suggestions when installing mobile amateur equipments in an EV/HEV.

EV AND HEV ARCHITECTURE

Most EVs and HEVs have similar electrical traction system (ETS) architectures consisting of a high voltage battery supplying energy to an inverter which controls an electric motor within a transmission connected to the drive wheels. The main difference between the two is that an HEV includes an internal combustion engine to aid in propulsion and a pure EV is strictly electrically powered.

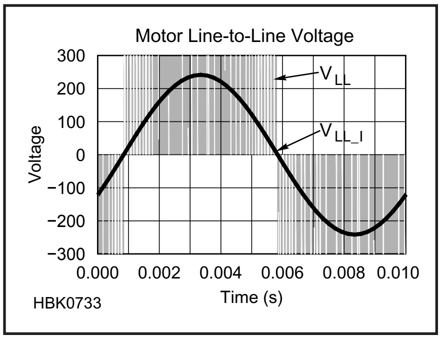


Fig 27.30 — Phase-to-phase motor terminal voltage.

The heart of the ETS is a device called an inverter. It simply converts dc voltage from the high voltage battery (typical voltage range from 42 to 350 V dc) to an ac waveform supplying the electric motor. This dc-to-ac conversion is performed by a matrix of six transistor switches. The switches chop the dc voltage into systematically varying pulses called pulse-width-modulation (PWM) to form an adjustable frequency and RMS voltage suitable to power electric motor.

In most cases, the ac voltage from the inverter is a three-phase waveform similar to industrial applications because three-phase motors can be smaller, more efficient, and provide greater torque than single-phase motors.

IMPORTANT — Bright orange cables connect the battery pack to the inverter and the inverter to the drive motor, transferring voltage and current to and from the inverter. Because of the non-sinusoidal waveforms being transferred, these cables are shielded and terminated at each end. Under no condition should these cables be disconnected or modified, because the high voltage system depends on a delicate balance of sensors and safety mechanisms. Possible malfunction and damage to the ETS may occur if modified.

EV AND HEV RFI CONCERNS

The inverter uses PWM to convert dc battery voltage to an ac waveform. The phase-to-phase terminal voltage appears in **Fig 27.30** as rectangular blocks with positive and negative amplitude equal to the battery voltage. For example, a 300 V dc battery pack will provide 600 V peak-to-peak at the motor terminals. In Fig 27.30, the same terminal voltage signal is sent through a low pass filter to show how PWM forms a sinusoidal waveform. Each pulse is essentially a square wave. Harmonics from these pulses fall within most of our amateur HF bands, affecting radio performance. Because EV/HEV systems are evolving rapidly, check the ARRL's Automotive RFI web page (**www.arrl.org/automotive**) for more information.

EV AND HEV RFI REMEDIES

Troubleshooting techniques described earlier apply in diagnosing RFI from EV/HEV systems. Limited RFI remedies are available associated to components within the ETS. Work with your dealer when you suspect the ETS as the RFI source. Do not attempt to modify or repair your ETS; the dealer's service center is most qualified to inspect and repair your EV/HEV electrical traction system.

During installation, mobile equipment power cables and antenna coaxial cables should be routed as far as possible from the bright orange cables. Common-mode chokes can decrease noise on 12-V dc power cables. Additionally, antenna placement plays a critical role in mobile equipment performance. Areas such as the top of a roof or trunk sometimes provide additional shielding.

27.9.6 Automotive RFI Summary

Most radio installations should result in no problems to either the vehicle systems or any issues with the transceiver. However, manufacturer, make and models differ, thus introducing challenges during amateur equipment installations.

Begin by researching your vehicle of interest and visiting the dealer. Insist on transmitting and receiving your favorite frequencies as you test drive. Request information pertaining to the manufacturer's transceiver installation guidelines. If manufacturer information is not available, follow the guidelines described earlier.

After installation, RFI problems may appear. Report you problem to the dealer, because they have access to manufacturer service bulletins which may describe a repair solution. Additional troubleshooting and remedies are also described previously to assist in successful communication.

Limited RFI remedies are available associated to components within the ETS. Work with your dealer when you suspect the ETS is the RFI source. Do not attempt to modify or repair your ETS; the dealer's service center is most qualified to inspect and repair your EV/HEV electrical traction system.

Lastly, the latest version of the *ARRL RFI Book* contains additional information on RFI in automobiles. More details are given about noise sources, troubleshooting techniques, a troubleshooting flow chart, additional filtering techniques, and information on EV/HEVs.

27.10 RFI Projects

Note: Additional RFI projects appear on the CD accompanying this book.

27.10.1 *Project*: RF Sniffer

Every home is full of electrical equipment capable of emitting electromagnetic radiation to interfere with radio amateurs trying to listen to signals on the bands. This project detects the radiation that causes problems to the amateur, and the noise can be heard. This device will allow you to demonstrate the "noise" with which we have to contend.

CONSTRUCTION

The circuit (**Fig 27.31**) uses a telephone pick-up coil as a detector, the output of which is fed into a LM741 IC preamplifier, followed by a LM386 IC power amplifier. See **Table 27.4** for the complete component list.

The project is built on a perforated board (**Fig 27.32**), with the component leads pushed

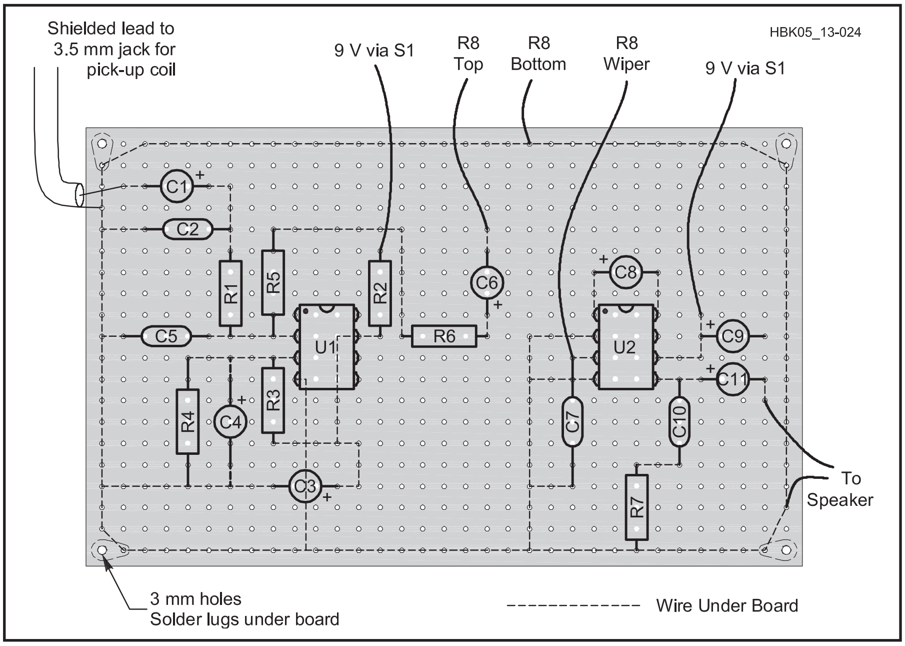


Fig 27.32 — The project is built on perforated board with point-to-point wiring underneath.

Table 27.4
Components List

Resistors	Value
R1	1 kΩ
R2, R6	100 Ω
R3, R4	47 kΩ
R5	100 kΩ
R7	10 Ω
R8	10 kΩ, with switch

Capacitors	Value
C1, C6	4.7 µF, 16 V electrolytic
C2, C5	0.01 µF
C3, C4	22 µF, 16 V electrolytic
C7	0.047 µF
C8	10 µF, 16 V electrolytic
C9, C11	330 µF, 16 V electrolytic
C10	0.1 µF

Semiconductors	
U1	LM741
U2	LM386

Additional Items	
LS1	Small 8-Ω loudspeaker
Perforated board	
9 V battery and clip	
3.5 mm mono-jack socket	
Case	
Telephone pick-up coil	

Table 27.5
Readings (pick-up coil near household items)

29-MHz oscilloscope	0.56 V
Old computer CRT monitor	0.86 V
Old computer with plastic case	1.53 V
New computer CRT monitor	0.45 V
New tower PC with metal case	0.15 V
Old TV	1.2 V
New TV	0.4 V
Plastic-cased hairdryer	4.6 V
Vacuum cleaner	3.6 V
Drill	4.9 V

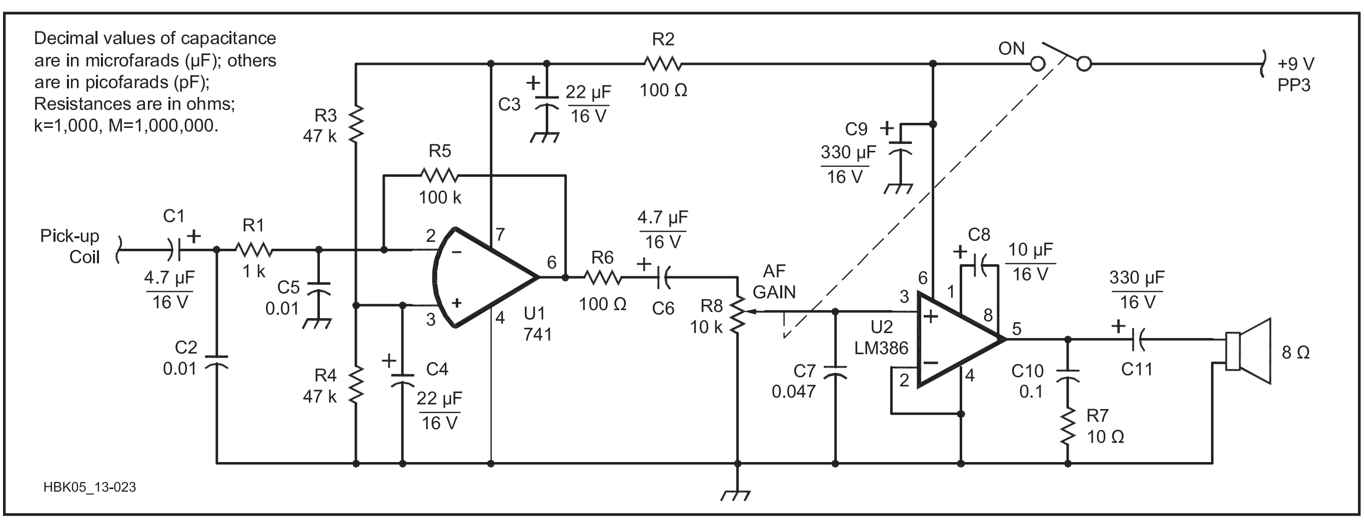


Fig 27.31 — The detector works by receiving stray radiation on a telephone pick-up coil and amplifying it to loudspeaker level.

through the holes and joined with hook-up wire underneath. There is a wire running around the perimeter of the board to form an earth bus.

Build from the loudspeaker backwards to R8, apply power and touch the wiper of R8. If everything is OK you should hear a loud buzz from the speaker. Too much gain may cause a feedback howl, in which case you will need to adjust R8 to reduce the gain. Complete the rest of the wiring and test with a finger on the input, which should produce a click and a buzz. The pick-up coil comes with a lead and 3.5 mm jack, so you will need a suitable socket.

RELATIVE NOISES

Place a high-impedance meter set to a low-ac-voltage range across the speaker leads to give a comparative readout between different items of equipment in the home. Sample readings are shown in **Table 27.5**.

27.11 RFI Glossary

Balanced circuit — A circuit whose two conductors have equal impedance to a common reference, such as a reference plane or circuit common.

Bond — (noun) A low-impedance, mechanically robust, electrical connection.

Common-mode — A voltage or current that is equal, in phase, and has the same polarity on all conductors of a cable. Common-mode current excites a cable as an antenna, and a cable acting as a receiving antenna produces common-mode current.

Conducted RFI — RFI received via a conducting path.

Coupled RFI — RFI received via inductive or capacitive coupling between conductors.

Differential mode — A signal that that is exists and is transmitted as a voltage *between* two conductors of a cable. At any instant, signal current on one conductor is equal to but of the opposite polarity to the current on the other conductor. Ordinary connections between equipment in systems are differential mode signals.

Disturbance — The improper operation of a device as a result of interference.

Electric field — The field present between two or more conductive objects as a result of potential difference (voltage) between those objects.

Electromagnetic field — The combination of a magnetic field and electric field in which the fields are directly related to each other, are at right angles to each other, and move through space as radio waves in a direction that is mutually perpendicular to both fields. An electrical conductor designed to produce electromagnetic fields when carrying an RF current is called an antenna.

Equipment ground — The connection of all exposed parts of electrical equipment to earth, or to a body that serves in place of earth.

Fundamental overload — 1. (Receiver Performance) Interference to a receiver caused by a signal at its input whose amplitude exceeds the maximum signal-handling capabilities of one or more receiver stages. 2. (RF interference) — Any disruption to the function of any RFI victim caused by the fundamental component of a transmitted signal or intended in-band output of a transmitter.

Ground — 1. A low impedance electrical connection to earth, or to a body that serves in place of earth. 2. A common signal connection in an electrical circuit.

Immunity — The ability of a device to function properly in the presence of unwanted electromagnetic energy. (After Ott, section 1.3)

Intentional radiator — A device that uses radio waves to transmit information by antenna action. A radio transmitter, with its associated antenna, is an intentional radiator.

Interference — 1. Disruption of a device's normal function as a result of an electromagnetic field, voltage, or current. 2. Disruption by a signal or noise of a receiver's ability to acquire and process a desired signal.

Magnetic field — The field produced by a permanent magnet or current flow through a conductor.

Path — The route by which electromagnetic energy is transferred from a transmitter to a receiver or from a source to a victim.

Radiated RFI — RFI received through radiation.

Shielding — A conductive barrier or enclosure interposed between two regions of space with the intent of preventing a field in one region from reaching the other region.

Source — A device that produces an electromagnetic, electric, or magnetic field, voltage, or current. If RFI is the result, the source is an *RFI source*.

Spurious emission — An emission outside the bandwidth needed for transmission of the mode being employed, the level of which may be reduced without reducing the quality of information being transmitted. Spurious emissions are most commonly the products of distortion (harmonics, intermodulation), of circuit instability (oscillation, including RF feedback), or of digital transmission with excessively fast rise times (including key clicks). Phase noise, such as that produced by a frequency synthesizer is also a spurious emission.

Susceptibility — The capability of a device to respond to unwanted electromagnetic energy. (After Ott, section 1.3)

System ground — A bond between one current-carrying conductor of the power system and earth.

Unintentional radiator — A device that produces RF as part of its normal operation but does not intentionally radiate it.

Victim — A device that receives interference from a *source*.

27.12 References and Bibliography

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M. Loftness, *AC Power Interference*, Third Edition, Revised, distributed by the ARRL

H. Ott, *Electromagnetic Compatibility Engineering*, John Wiley and Sons, 2009

C. Paul, *Introduction to Electromagnetic Compatibility*, Wiley-Interscience, 1992

AES48-2005: AES standard on interconnections — Grounding and EMC practices — Shields of connectors in audio equipment containing active circuitry

Underwriter Labs Standard UL943, "Ground-Fault Circuit-Interrupters," **http://ulstandardsinfonet.ul.com/scopes/scopes.asp?fn=0943.html**

Contents

**Chapter 28 —
CD-ROM Content**

Supplemental Files

- *Electric Current Abroad* — U.S. Dept of Commerce
- “Shop Safety” by Don Daso, K4ZA
- “RF Safety at Field Day” by Greg Lapin, N9GL
- “Field Day Towers — Doing It Right” by Don Daso, K4ZA and Ward Silver, NØAX

Chapter 28

Safety

This chapter focuses on how to avoid potential hazards as we explore Amateur Radio and its many facets. The first section, updated by Jim Lux, W6RMK, details electrical safety, grounding and other issues in the ham shack. The following section on antenna and tower safety was written by Steve Morris, K7LXC, a professional tower climber and antenna installer with many years of experience. Finally, the ARRL RF Safety Committee explains good amateur practices, standards and FCC regulations as they apply to RF safety.

Safety First — Always

We need to learn as much as possible about what could go wrong so we can avoid factors that might result in accidents. Amateur Radio activities are not inherently hazardous, but like many things in modern life, it pays to be informed. Stated another way, while we long to be creative and innovative, there is still the need to act responsibly. Safety begins with our attitude. Make it a habit to plan work carefully. Don't be the one to say, "I didn't think it could happen to me."

Having a good attitude about safety is not enough, however. We must be knowledgeable about common safety guidelines and follow them faithfully. Safety guidelines cannot possibly cover all situations, but if we approach each task with a measure of common sense, we should be able to work safely.

Involve your family in Amateur Radio. Having other people close by is always beneficial in the event that you need immediate assistance. Take the valuable step of showing family members how to turn off the electrical power to your equipment safely. Additionally, cardiopulmonary resuscitation (CPR) training can save lives in the event of electrical shock. Classes are offered in most communities. Take the time to plan with your family members exactly what action should be taken in the event of an emergency, such as electrical shock, equipment fire or power outage. Practice your plan!

28.1 Electrical Safety

The standard power available from commercial mains in the United States for residential service is 120/240-V ac. The "primary" voltages that feed transformers in our neighborhoods may range from 1300 to more than 10,000 V. Generally, the responsibility for maintaining the power distribution system belongs to a utility company, electric cooperative or city. The "ownership" of conductors usually transfers from the electric utility supplier to the homeowner where the power connects to the meter or weather head. If you are unsure of where the division of responsibility falls in your community, a call to your electrical utility will provide the answer. **Fig 28.1** shows the typical division of responsibility between the utility company and the homeowner. This section is concerned more with wiring practices in the shack, as opposed to within the equipment in the shack.

There are two facets to success with electrical power: safety and performance. Since we are not professionals, we need to pursue safety first and consult professionals for alternative solutions if performance is unacceptable. The ARRL's Volunteer Consulting Engineers program involves professional engineers who may be able to provide advice or direction on difficult problems.

28.1.1 Station Concerns

There never seem to be enough power outlets in your shack. A good solution for small scale power distribution is a switched power strip with multiple outlets. The strip should be listed by a nationally recognized testing laboratory (NRTL) such as Underwriters Lab, UL, and should incorporate a circuit breaker. See the sidebars "What Does UL Listing Mean?" and "How Safe are Outlet Strips?" for warnings about poor quality products. It is poor practice to "daisy-chain" several power strips

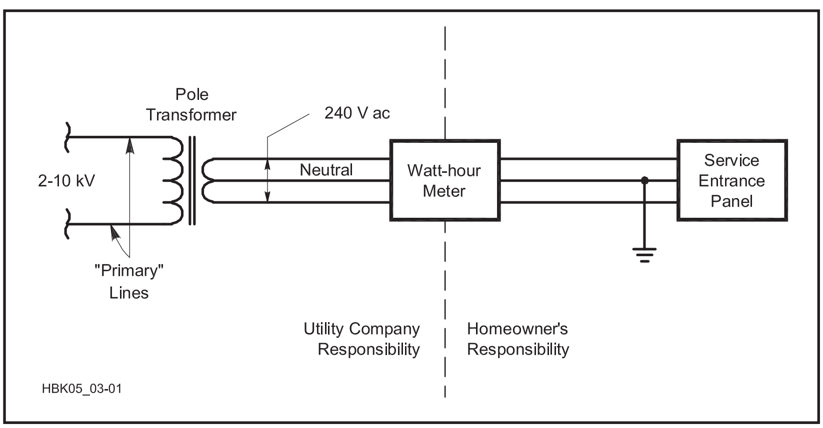


Fig 28.1 — Typical division of responsibility for maintenance of electrical power conductors and equipment. The meter is supplied by the utility company.

What Does UL Listing Mean?

UL is one of several nationally recognized testing laboratories (NRTLs), and probably the most well known. Listing *does not* mean what most consumers expect it to mean! More often than not the listing *does not* relate to the performance of the listed product. The listing simply indicates that a sample of the device meets certain manufacturers' construction criteria. Similar devices from the same or different manufacturers may differ significantly in overall construction and performance even though all are investigated and listed against the same UL product category. There is also a difference between a listed device and a listed component.

Many local laws and regulations, as well as the *NEC*, require that equipment and components used in electrical installations be listed by a NRTL. Some jurisdictions (Los Angeles County) require that any electrical equipment sold to consumers be listed.

The consumer must also be aware of the fine distinctions in advertising between a device or component that is advertised as "listed" or "designed to meet" or "meets." The latter two may not actually have been tested, or if tested, may have been tested by the manufacturer, and not an independent body.

It's also important to know that in some cases UL (and other standards organizations) only publish a standardized test procedure, but don't necessarily list or test the devices. Many standards also define varying levels of compliance, so knowing that your device meets some part of the standard may not be enough to know whether it meets *your* particular needs.

How Safe Are Outlet Strips?

The switch in outlet strips is generally *not* rated for repetitive *load break* duty. Early failure and fire hazard may result from using these devices to switch loads. Misapplications are common (another bit of bad technique that has evolved from the use of personal computers), and manufacturers are all too willing to accommodate the market with marginal products that are "cheap."

Nonindicating and poorly designed surge protection also add to the safety hazard of using power strips. MOVs with too low a threshold voltage often fail in a manner that could cause a fire hazard, especially in outlet strips that have nonmetallic enclosures, because day-to-day voltage surges that are otherwise unexceptional degrade the MOV each time, until it fails shorted.

A lockable disconnect switch or circuit breaker is a better and safer station master switch.

and may actually be a code violation. If you need more outlets than are available on a strip, have additional wall outlets installed.

Whether you add new outlets or use power strips, be sure not to overload the circuit. National and local codes set permissible branch capacities according to a rather complex process. Here's a safe rule of thumb: consider adding a new circuit if the total load is more than 80% of the circuit breaker or fuse rating. (This assumes that the fuse or breaker is correct. If you have any doubts, have an electrician check it.)

28.1.2. Do-It-Yourself Wiring

Amateurs sometimes "rewire" parts of their homes to accommodate their hobby. Most local codes *do* allow for modification of wiring (by building owners), so long as the electrical codes are met. Before making changes to your wiring, it would be wise to determine what rules apply and what agency has the authority to enforce them. This is called the *authority having jurisdiction* (AHJ) and it varies from location to location. Also see the following section on the National Electrical Code.

Generally, the building owner must obtain an electrical permit before beginning changes or additions to permanent wiring. Some jobs may require drawings of planned work. Often the permit fee pays for an inspector to review the work. Considering the risk of injury or fire if critical mistakes are left uncorrected, a permit and inspection are well worth the effort. *Don't take chances* — seek assistance from the building officials or an experienced electrician if you have *any* questions or doubts about proper wiring techniques.

Ordinary 120-V circuits are the most common source of fatal electrical accidents. Line voltage wiring must use an approved cable, be properly installed in conduit and junction boxes, within a chassis with a cover or lid, or other means described in the electrical code. Remember that high-current, low-voltage power sources, such as car batteries and high-current power supplies, can be just as dangerous as high-voltage sources, from melting metal, sparks and short circuits.

Never work on electrical wiring with the conductors energized! Switch off the circuit breaker or remove the fuse and take positive steps to ensure that others do not restore the power while you are working, such as using a circuit-breaker lockout. (**Fig 28.2** illustrates one way to ensure that power will be off until you want it turned on.) Check the circuit with an ac voltmeter to be sure that it is "dead" *each time you begin work*.

Before restoring power, check the wiring with an ohmmeter: From the installed outlet, there should be good continuity between the neutral conductor (white wire, "silver" screw) and the grounding conductor (green or bare wire, green screw). An ohmmeter should indicate a closed circuit between the conductors. (In the power line, high voltage world, line workers apply a shorting jumper before starting work so if the power does get reapplied, the safety jumper takes the hit.)

There should be no continuity between the hot conductor (black wire, "brass" screw) and the grounding conductor or the neutral conductor. With all other loads removed from the circuit (by turning off or unplugging them), an ohmmeter should indicate an *open* circuit between the hot wire and either of the other two conductors.

Commercially available plug-in testers are a convenient way to test regular three-wire receptacles, but can't distinguish between the neutral and ground being reversed

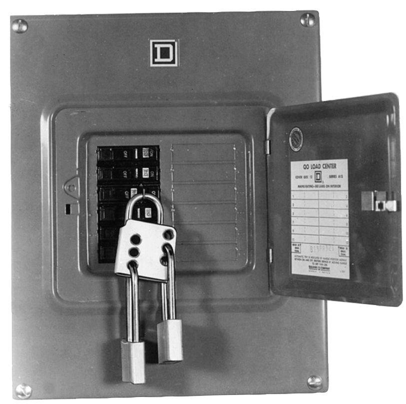


Fig 28.2 — If the switch box feeding power to your shack is equipped with a lock-out hole, use it. With a lock through the hole on the box, the power cannot be accidentally turned back on. *(Photo courtesy of American ED-CO)*

28.1.3 National Electrical Code (NEC)

Fortunately, much has been learned about how to harness electrical energy safely. This collective experience has been codified into the *National Electrical Code*, or *NEC*, simply known as "the code." The code details safety requirements for many kinds of electrical installations. Compliance with the *NEC* provides an installation that is *essentially* free from hazard, but not necessarily efficient,

convenient or adequate for good service (paraphrased from NEC Article 90-1a and b). While the *NEC* is national in nature and sees wide application, it is not universal.

Local building authorities set the codes for their area of jurisdiction. They often incorporate the *NEC* in some form, while considering local issues. For example, Washington State specifically exempts telephone, telegraph, radio and television wires and equipment from conformance to electrical codes, rules and regulations. However, some local jurisdictions (city, county and so on) do impose a higher level of installation criteria, including some of the requirements exempted by the state.

Code interpretation is a complex subject, and untrained individuals should steer clear of the *NEC* itself. The *NEC* is not written to be understood by do-it-yourselfers, and one typically has to look in several places to find *all* the requirements. (For instance, Articles 810, 250, *and* 100 all contain things applicable to typical Amateur Radio installations.) Therefore, the best sources of information about code compliance and acceptable practices are local building officials, engineers and practicing electricians.

The Internet has a lot of information about electrical safety, the electrical code, and wiring practices, but you need to be careful to make sure the information you are using is current and not out of date. The ARRL Volunteer Consulting Engineer (VCE) program can help you find a professional who understands the amateur radio world, as well as the regulatory environment. There are also a variety of websites with useful information (such as **www.mikeholt.com**), but you need to be aware that advice may be specific to a particular installation or jurisdiction and not applicable for yours. With that said, let's look at a few *NEC* requirements for radio installations.

HOMEBREW AND "THE CODE"

In many cases, there are now legal requirements that electrical equipment have been listed by an NRTL, such as Underwriter Laboratories. This raises an issue for hams and homebrew gear, since it's unlikely you would take your latest project down to a test lab and pay them to evaluate it for safety.

For equipment that is not permanently installed, there's not much of an issue with homebrew, as far as the code goes, because the code doesn't deal with what's inside the equipment. For a lot of low voltage equipment, the code rules are fairly easy to meet, as well, as long as the equipment is supplied by a listed power source of the appropriate type.

The problem arises with permanent installations, where the scope of the code and local regulations is ever increasing. Such things as solar panel installations, standby generators, personal computers and home LANs all have received increased attention in local codes.

About the National Electrical Code

Exactly how does the National Electrical Code become a requirement? How is it enforced?

Cities and other political subdivisions have the responsibility to act for the public safety and welfare. To address safety and fire hazards in buildings, regulations are adopted by local laws and ordinances usually including some form of permit and accompanying inspections. Because the technology for the development of general construction, mechanical and electrical codes is beyond most city building departments, model codes are incorporated by reference. There are several general building code models used in the US: Uniform, BOCA and Southern Building Codes are those most commonly adopted. For electrical issues, the *National Electrical Code* is in effect in virtually every community. City building officials will serve as "the authority having jurisdiction" (AHJ) and interpret the provisions of the *Code* as they apply it to specific cases.

Building codes differ from planning or zoning regulations: Building codes are directed only at safety, fire and health issues. Zoning regulations often are aimed at preservation of property values and aesthetics.

The *NEC* is part of a series of reference codes published by the National Fire Protection Association, a non-profit organization. Published codes are regularly kept up-to-date and are developed by a series of technical committees whose makeup represents a wide consensus of opinion. The *NEC* is updated every three years. It's important to know which version of the code your local jurisdiction uses, since it's not unusual to have the city require compliance to an older version of the code. Fortunately, the *NEC* is usually backward compatible: that is, if you're compliant to the 2008 code, you're probably also compliant to the 1999 code.

Do I have to update my electrical wiring as code requirements are updated or changed?

Generally, no. Codes are typically applied for new construction and for renovating existing structures. Room additions, for example, might not directly trigger upgrades in the existing service panel unless the panel was determined to be inadequate. However, the wiring of the new addition would be expected to meet current codes. Prudent homeowners, however, may want to add safety features for their own value. Many homeowners, for example, have added GFCI protection to bathroom and outdoor convenience outlets.

28.1.4 Station Power

Amateur Radio stations generally require a 120-V ac power source, which is then converted to the proper ac or dc levels required for the station equipment. In residential systems voltages from 110 V through 125 V are treated equivalently, as are those from 220 V through 250 V. Amateurs setting up a station in a light industrial or office environment may encounter 208 V line voltage. Most power supplies operate over these ranges, but it's a good idea to measure the voltage range at your station. (The measured voltage usually varies by hour, day, season and location.) Power supply theory is covered in the **Power Sources** chapter.

Modern solid state rigs often operate from dc power, provided by a suitable dc power supply, perhaps including battery backups. Sometimes, the dc power supply is part of the rig (as in a 50-V power supply for a solid-state linear). Other times, your shack might have a 12-V (13.8 V) bus that supplies many devices. Just because it's low voltage doesn't mean that there aren't aspects of the system that raise safety concerns. A 15-A, 12-V power supply can start a fire as easily as a 15-A, 120-V branch circuit.

28.1.5 Connecting and Disconnecting Power

Something that is sometimes overlooked is that you need to have a way to safely disconnect all power to everything in the shack. This includes not only the ac power, but also battery banks, solar panels, and uninterruptible power supplies (UPS). Most hams won't have the luxury of a dedicated room with a dedicated power feed and the "big red switch" on the wall, so you'll have several switches and cords that would need to be disconnected.

The realities of today's shacks, with computers, multiple wall transformers ("wall-warts"), network interfaces and the radio equipment itself makes this tricky to do. One convenient means is a switched outlet strip, as used for computer equipment, if you have a limited number of devices. If you need more switched outlets, you can control multiple low-voltage controlled switched outlets from a common source. Or you can build or buy a portable power distribution box similar to those used on construction sites or stage sets; they are basically a portable subpanel with individual circuit breakers (or GFCIs, discussed later) for each receptacle, and fed by a suitable cord or extension cord. No matter what scheme you use, however, it's important that it be labeled so that someone else will know what to do to turn off the power.

> ## International Power Standards
>
> The power grid of the United States and Canada uses a frequency of 60 Hz and the voltage at ac power outlets is 120 V. This is also the case in other North American countries. If you travel, though, you'll encounter 220 V and 50 Hz with quite an array of plugs and sockets and color codes. If you are planning on taking amateur radio equipment with you on a vacation or DXpedition, you'll need to be prepared with the proper adapters and/or transformers to operate your equipment.
>
> A table of international voltage and frequencies is provided on the CD-ROM accompanying this book, along with a figure showing the most common plug and socket configurations.

AC LINE POWER

If your station is located in a room with electrical outlets, you're in luck. If your station is located in the basement, an attic or other area without a convenient 120-V source, you may need to have a new line run to your operating position.

Stations with high-power amplifiers should have a 240-V ac power source in addition to the 120-V supply. Some amplifiers may be powered from 120 V, but they require current levels that may exceed the limits of standard house wiring. To avoid overloading the circuit and to reduce household light dimming or blinking when the amplifier is in use, and for the best possible voltage regulation in the equipment, it is advisable to install a separate 240 or 120-V line with an appropriate current rating if you use an amplifier.

The usual circuits feeding household outlets are rated at 15 or 20 A., This may or may not be enough current to power your station. To determine how much current your station requires, check the VA (volt-amp) ratings for each piece of gear. (See the **Electrical Fundamentals** chapter for a discussion of VA.) Usually, the manufacturer will specify the required current at 120 V; if the power consumption is rated in watts, divide that rating by 120 V to get amperes. Modern switching power supplies draw more current as the line voltage drops, so if your line voltage is markedly lower than 120 V, you need to take that into account.

Note that the code requires you to use the "nameplate" current, even if you've measured the actual current, and it's less. If the total current required is near 80% of the circuit's rating (12 A on a 15-A circuit or 16 A on a 20-A circuit), you need to install another circuit. Keep in mind that other rooms may be powered from the same branch of the electrical system, so the power consumption of any equipment connected to other outlets on the branch must be taken into account. If you would like to measure just how much power your equipment consumes, the inexpensive Kill-A-Watt meters by P3 International (**www.p3international.com**) measure volts, amps, VA and power factor.

If you decide to install a separate 120-V line or a 240-V line, consult the local requirements as discussed earlier. In some areas, a licensed electrician must perform this work. Others may require a special building permit. Even if you are allowed to do the work yourself, it might need inspection by a licensed electrician. Go through the system and get the necessary permits and inspections! Faulty wiring can destroy your possessions and take away your loved ones. Many fire insurance policies are void if there is unapproved wiring in the structure.

If you decide to do the job yourself, work closely with local building officials. Most home-improvement centers sell books to guide do-it-yourself wiring projects. If you have any doubts about doing the work yourself, get a licensed electrician to do the installation.

THREE-WIRE 120-V POWER CORDS

Most metal-cased electrical tools and appliances are equipped with three-conductor power cords. Two of the conductors carry power to the device, while the third conductor is connected to the case or frame. **Fig 28.3** shows two commonly used connectors.

When both plug and receptacle are properly wired, the three-contact polarized plug bonds the equipment to the system ground. If an internal short from line to case occurs, the "ground" pin carries the fault current and hopefully has a low enough impedance to trip the branch circuit breaker or blow the fuse in the device. A second reason for grounding the case is to reduce the possibility of shock for a user simultaneously connected to ground and the device. In modern practice, however, shock prevention is often done with GFCI circuit breakers as described below. These devices trip at a much lower level and are more reliable. Most commercially manufactured test equipment and ac-operated amateur equipment is supplied with three-wire cords.

It's a good idea to check for continuity from case to ground pin, particularly on used equipment, where the ground connection might have been broken or modified by the previous owner. If there is no continuity, have the equipment repaired before use.

Use such equipment only with properly installed three-wire outlets. If your house does not have such outlets, either consult a local electrician to learn about safe alternatives or have a professional review information you might obtain from online or other sources.

Equipment with plastic cases is considered "double insulated" and fed with a two-wire cord. Such equipment is safe because both conductors are insulated from the user by two layers. Nonetheless, there is still a hazard if, say, a double insulated drill were used to drill an improperly grounded case of a transmit-

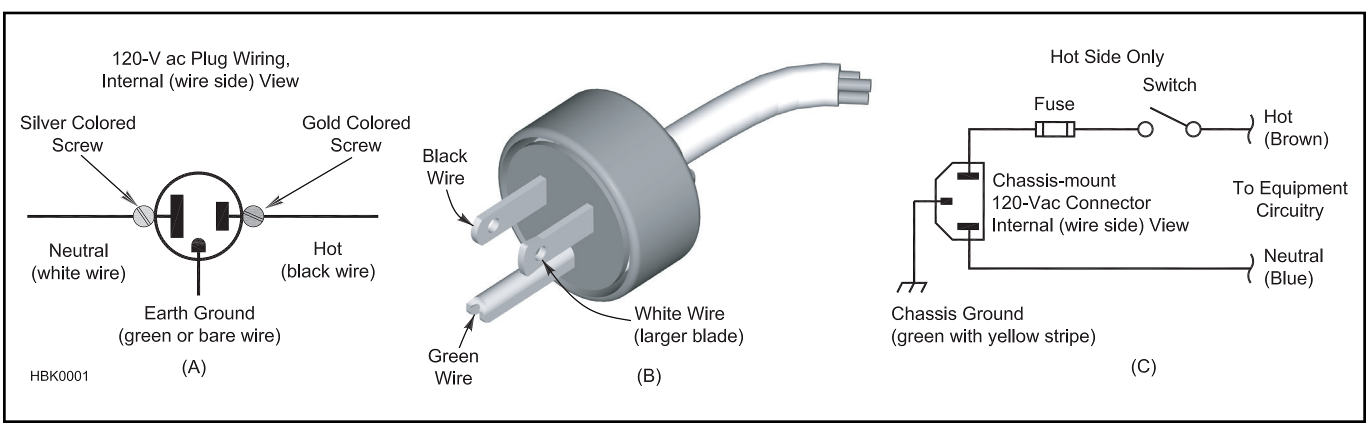


Fig 28.3 — 120 V ac plug wiring as viewed from the wire side (A) and viewed from the blade side (B). Wiring for an IEC type chassis connector is shown at C.

ter that was still plugged in. Remember, all insulation is prey to age, damage and wear that may erode its initial protection.

TRANSFER SWITCHES AND GENERATORS

More hams are adding standby generators and using alternate power sources such as solar panels or wind turbines, not as standalone systems like at Field Day, but interconnected with their home electrical system. These present some potential safety problems, such as preventing the local generator from "back-feeding" the utility's system during a power failure, and the fact that a solar panel puts out power whenever there is light falling on it.

For generators, the recommended approach is to use a *transfer switch*, which is a multi-pole switch that connects a selection of the house's circuits to the generator, rather than the utility power. The *NEC* and local regulations should be consulted for transfer switch selection and connection. The required wiring practices for permanently installed (stationary) generators are different from those for portable generators. Some issues that need to be considered are whether the neutral should be switched (many transfer switches do not switch the neutral, only the hot wire), and how the generator chassis is bonded to the building's grounding/bonding system. Most proper transfer switches are of the ON-OFF-ON configuration, with a mechanical interlock that prevents directly switching from one source to the other in a single operation.

The most dangerous thing to do with a generator is to use a so-called "suicide cord" with a male plug at each end: one end plugged into the generator's output receptacle and the other plugged into a convenient receptacle in the home. This is frequently illegal and at any rate should be avoided because of the inherent danger of having exposed, live contacts and the ease of overloading the circuit being fed.

Back-feeding your home's power panel should *never* be done unless the main breakers are in the OFF position or preferably removed. If your home's circuit-breaker panel does not have main breakers that can disconnect the external power line, *do not* use this technique to connect your generator to the home's wiring. Connect appliances to the generator directly with extension cords.

Table 28.1
Traditional Divisions Among the Classes of Circuits

Class	*Power*	*Notes*
Class 1		
Power Limited	<30V, <1000VA	Transformer protected per Article 450. If not transformer, other overcurrent and fault protection requirements apply
Remote Control and Signaling	<600V	No limit on VA Transformers protected as defined in Article 450
Class 2	Power supply <100VA Voltage <30V	
Class 3	Power supply <100VA Voltage <100V	

28.1.6 Ground-Fault and Arc-Fault Circuit Interrupters

GFCIs are devices that can be used with common 120 V household circuits to reduce the chance of electrocution when the path of current flow leaves the branch circuit (say, through a person's body to another branch or ground). An AFCI is similar in that it monitors current to watch for a fault condition. Instead of current imbalances, the AFCI detects patterns of current that indicate an arc — one of the leading causes of home fires. The AFCI is not supposed to trip because of "normal" arcs that occur when a switch is opened or a plug is removed.

The *NEC* requires GFCI outlets in all wet or potentially wet locations, such as bathrooms, kitchens, and any outdoor outlet with ground-level access, garages and unfinished basements. AFCI protection is required for all circuits that supply bedrooms. Any area with bare concrete floors or concrete masonry walls should be GFCI equipped. GFCIs are available as portable units, duplex outlets and as individual circuit breakers. Some early units may have been sensitive to RF radiation but this problem appears to have been solved. Ham radio shacks in potentially wet areas (basements, out buildings) should be GFCI equipped. **Figure 28.4** is a simplified diagram of a GFCI.

Older equipment with capacitors in the 0.01 µF to 0.1 µF range connected between line inputs and chassis as an EMI filter (or that has been modified with bypass capacitors) will often cause a GFCI to trip, because of the leakage current through the capacitor. The must-trip current is 5 mA, but many GFCIs trip at lower levels. At 60 Hz, a 0.01 µF capacitor has an impedance of about 265 kΩ, so there could be a leakage current of about 0.5 mA from the 120 V line. If you had several pieces of equipment with such capacitors, the leakage current will trip the GFCI.

Some early GFCI breakers were susceptible to RFI but as the technology has improved, fewer and fewer such reports have been received. While it is possible to add filtering or RF suppression to the breaker wiring, a simpler and less expensive solution is to simply replace the GFCI breaker with a new unit less susceptible to RF. Reports have not yet been received on AFCI products. For more information on RFI and GFCI/AFCI devices, check the ARRL web page **www.arrl.org/gfci-devices**.

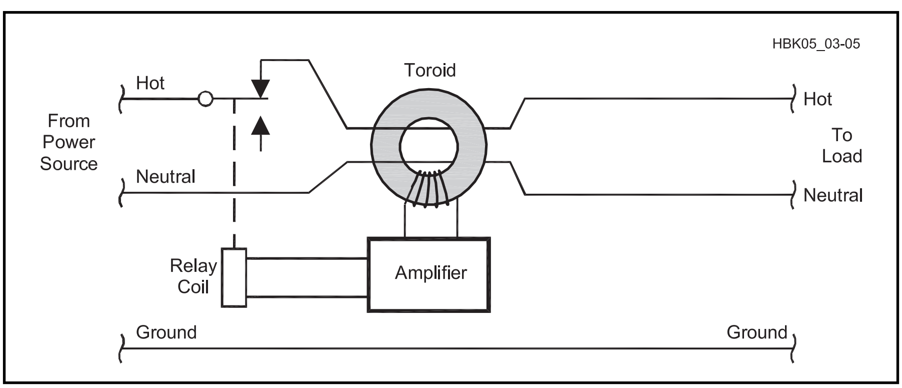


Fig 28.4 — Simplified diagram of a 120-V ac ground fault circuit interrupter (GFCI). When a stray current flows from the load (or outlet) side to ground, the toroidal current becomes unbalanced allowing detection, amplification and relay actuation to immediately cut off power to the load (and to the stray path!) GFCI units require a manual reset after tripping. GFCIs are required in wet locations (near kitchen sinks, in garages, in outdoor circuits and for construction work.) They are available as portable units or combined with over-current circuit breakers for installation in entrance panels.

28.1.7 Low-Voltage Wiring

Many ham shacks use low-voltage control wiring for rotators or antenna relays. The electrical code isn't consistent in what it calls low voltage, but a guideline is "less than 50 V." Article 725 of the code contains most of the rules for low voltage/low power remote control and signaling, which is what hams are typically doing. These circuits are divided into three classes, with Class 1 being further subdivided, as shown in **Table 28.1**. There used to be code rules defining the classes in terms of power and voltage, but these days, the code is written so that the class of the circuit is defined by the power source, which has to be listed and labeled with the class. That is, if you have something powered by a wall transformer that is listed and labeled as Class 2, the circuit is Class 2.

A typical example of a Class 1 Power Limited circuit that you might find in your home is 12 V low-voltage garden lighting or halogen lightning systems. A lot of amateur homebrew gear probably is also in this class, although because it's not made with "listed" components, it technically doesn't qualify. The other Class 1 would apply to a circuit using an isolation transformer of some sort.

Class 2 is very common: doorbells, network wiring, thermostats, and so on are almost all Class 2. To be Class 2, the circuit must be powered from a listed power supply that's marked as being Class 2 with a capacity less than 100 VA. For many applications that hams encounter, this will be the familiar "wall wart" power supply. If you have a bunch of equipment that runs from dc power, and you build a dc power distribution panel with regulators to supply them from a storage battery or a big dc power supply, you're most likely not Class 2 anymore, but logically Class 1. Since your homebrew panel isn't likely to be listed, you're really not even Class 1, but something that isn't covered by the code.

A common example of a Class 3 circuit that is greater than 30 V is the 70 V audio distribution systems used in paging systems and the like. Class 3 wiring must be done with appropriately rated cable.

WIRING PRACTICES

Low voltage cables must be separated from power circuits. Class 2 and 3 cannot be run with Class 1 low voltage cables. They can't share a cable tray or the same conduit. A more subtle point is that the 2005 code added a restriction [Article 725.56(F)] that audio cables (speakers, microphone, etc.) cannot be run in the same conduit with other Class 2 and Class 3 circuits (like network wiring).

Low voltage and remote control wiring should not be neglected from your transient suppression system. This includes putting appropriate protective devices where wiring enters and leaves a building, and consideration of the current paths to minimize loops which can pick up the field from transient (or RF from your antenna).

28.1.8 Grounds

As hams we are concerned with at least four kinds of things called "ground," even if they really aren't ground in the sense of connection to the Earth. These are easily confused because we call each of them "ground."

1) Electrical safety ground (bonding)
2) RF return (antenna ground)
3) Common reference potential (chassis ground)
4) Lightning and transient dissipation ground

IEEE Std 1100-2005 (also known as the "Emerald Book," see the Reference listing, section 28.1.13) provides detailed information from a theoretical and practical standpoint for grounding and powering electrical equipment, including lightning protection and RF EMI/EMC concerns. It's expensive to buy, but is available through libraries.

ELECTRICAL SAFETY GROUND (BONDING)

Power-line ground is required by building codes to ensure the safety of life and property surrounding electrical systems. The *NEC* requires that all grounds be *bonded* together; this is a very important safety feature as well as an *NEC* requirement.

The usual term one sees for the "third prong" or "green-wire ground" is the "electrical safety ground." The purpose of the third, non-load current carrying wire is to provide a path to insure that the overcurrent protection will trip in the event of a line-to-case short circuit in a piece of equipment. This could either be the fuse or circuit breaker back at the main panel, or the fuse inside the equipment itself.

There is a secondary purpose for shock reduction: The conductive case of equipment is required to be connected to the bonding system, which is also connected to earth ground at the service entrance, so someone who is connected to "earth" (for example, standing in bare feet on a conductive floor) that touches the case won't get shocked.

An effective safety ground system is necessary for every amateur station, and the code requires that all the "grounds" be bonded together. If you have equipment at the base of the tower, generally, you need to provide a separate bonding conductor to connect the chassis and cases at the tower to the bonding system in the shack. The electrical safety ground provides a common reference potential for all parts of the ac system. Unfortunately, an effective bonding conductor at 60 Hz may present very high impedance at RF because of the inductance, or worse yet, wind up being an excellent antenna that picks up the signals radiated by your antenna.

RF GROUND

RF ground is the term usually used to refer to things like equipment enclosures. It stems from days gone by when the long-wire antenna was king. At low enough frequencies, a wire from the chassis or antenna tuner in the shack to a ground rod pounded in outside the window had low RF impedance. The RF voltage difference between the chassis and "Earth ground" was small. And even if there were small potentials, the surrounding circuitry was relatively insensitive to them.

Today, though, we have a lot of circuits that are sensitive to interfering signals at millivolt levels, such as audio signals to and from sound cards. The summary is that we shouldn't be using the equipment enclosures or shielding conductors as part of the RF circuit.

Instead, we design our systems to create a common reference potential, called the "reference plane," and we endeavor to keep equipment connected to the reference plane at a common potential. This minimizes RF current that would flow between pieces of equipment. (See the **RF Interference** chapter for more information.)

Some think that RF grounds should be isolated from the safety ground system — *that is not true! All grounds, including safety, RF, lightning protection and commercial communications, must be bonded together in order to protect life and property.* The electrical code still requires that antenna grounds be interconnected (bonded) to the other "grounds" in the system, although that connection can have an RF choke. Remember that the focus of the electrical code bonding requirement

Grounding or Bonding?

You may notice the term "bonding" is replacing "grounding" in many instances. A primary safety concern is for whatever carries fault currents to be mechanically rugged and reasonably conductive. It's also important that the fault-carrying conductor be connected to a ground rod, but that's a different consideration. Bonding is the term to use when contact between pieces of equipment or between conductors is the primary concern. Grounding is the term to use when the electrical potential of the conductor is the most important.

is safety in the event of a short to a power distribution line or other transient.

COMMON REFERENCE POTENTIAL (CHASSIS GROUND)

For decades, amateurs have been advised to bond all equipment cabinets to an RF ground located near the station. That's a good idea, but it's not easily achieved. Even a few meters of wire can have an impedance of hundreds of ohms (1 µH/meter = 88 Ω/meter at 14 MHz). So a better approach is to connect the chassis together in a well-organized fashion to ensure that the chassis-to-chassis connections don't carry any RF current at all as in **Fig 28.5**. (See the **RF Interference** chapter for more information.)

LIGHTNING DISSIPATION GROUND

Lightning dissipation ground is concerned with conducting currents to the surrounding earth. There are distinct similarities between lightning dissipation ground systems and a good ground system for a vertical antenna. Since the lightning impulse has RF components around 1 MHz, it is an RF signal, and low inductance is needed, as well as low resistance.

The difference is that an antenna ground plane may handle perhaps a few tens of amps, while the lightning ground needs to handle a peak current of tens of kiloamperes.

A typical lightning stroke is a pulse with a rise time of a few microseconds, a peak current of 20-30 kA, and a fall time of 50 µs. The average current is not all that high (a few hundred amps), so the conductor size needed to carry the current without melting is surprisingly small.

However, large conductors are used in lightning grounds for other reasons: to reduce inductance, to handle the mechanical forces from the magnetic fields, and for ruggedness to prevent inadvertent breakage. A large diameter wire, or even better, a wide flat strap, has lower inductance. The voltage along a wire is proportional to the change in current and the inductance:

$$|V| \quad L\frac{di}{dt}$$

where

di/dt = rate of change in current, about 20kA/2µs for lightning, or 10^9 A/s, and

L = the inductance.

Consider a connection box on a tower that contains some circuitry terminating a control cable from the shack, appropriately protected internally with overvoltage protection. If the connection from the box to ground is high inductance, the lightning transient will raise the box potential (relative to the wiring coming from the shack), possibly beyond the point where the transient suppression in the box can handle it. Lowering the inductance of the connection to ground reduces the potential.

The other reason for large conductors on lightning grounds is to withstand the very high mechanical forces from the high currents. This is also the reason behind the recommendation that lightning conductors be run directly, with minimal bends, large radii for bends that are needed, and certainly no loops. A wire with 20,000 A has a powerful magnetic field surrounding it, and if current is flowing in multiple wires that are close to each other, the forces pushing the wires together or apart can actually break the conductors or deform them permanently.

The force between two conductors carrying 20,000 A, spaced a centimeter apart, is 8000 Newtons/meter of length (over 500 pounds/foot). Such forces can easily break cable strands or rip brackets and screws out. This problem is aggravated if there are loops in the wire, since the interaction of the current and its magnetic field tends to make the loop get larger, to the point where the wire will actually fail from the tension stresses.

GROUNDING METHODS

Earth ground usually takes one of several forms, all identified in the *NEC* and NFPA 780. The preferred earth ground, both as required in the NEC, and verified with years of testing in the field, is a concrete encased grounding electrode (CEGR), also known as a *Ufer ground*, after Herb Ufer, who invented it as a way to provide grounding for military installations in dry areas where ground rods are ineffective. The CEGR can take many forms, but the essential aspect is that a suitable conductor at least 20 feet long is encased in concrete which is buried in the ground. The conductor can be a copper wire (#8 AWG at least 20 ft long) or the reinforcing bars (rebar) in the concrete, often the foundation footing for the building. The connection to the rebar is either with a stub of the rebar protruding through the concrete's top surface or the copper wire extending through the concrete. There are other variations of the CEGR described in the *NEC* and in the electrical literature, but they're all functionally the same: a long conductor embedded in a big piece of concrete.

The electrode works because the concrete has a huge contact area with the surrounding soil, providing very low impedance and, what's also important, a low current density, so that localized heating doesn't occur. Concrete tends to absorb water, so it is also less susceptible to problems with the soil drying out around a traditional ground rod.

Ground rods are a traditional approach to making a suitable ground connection and are appropriate as supplemental grounds, say at

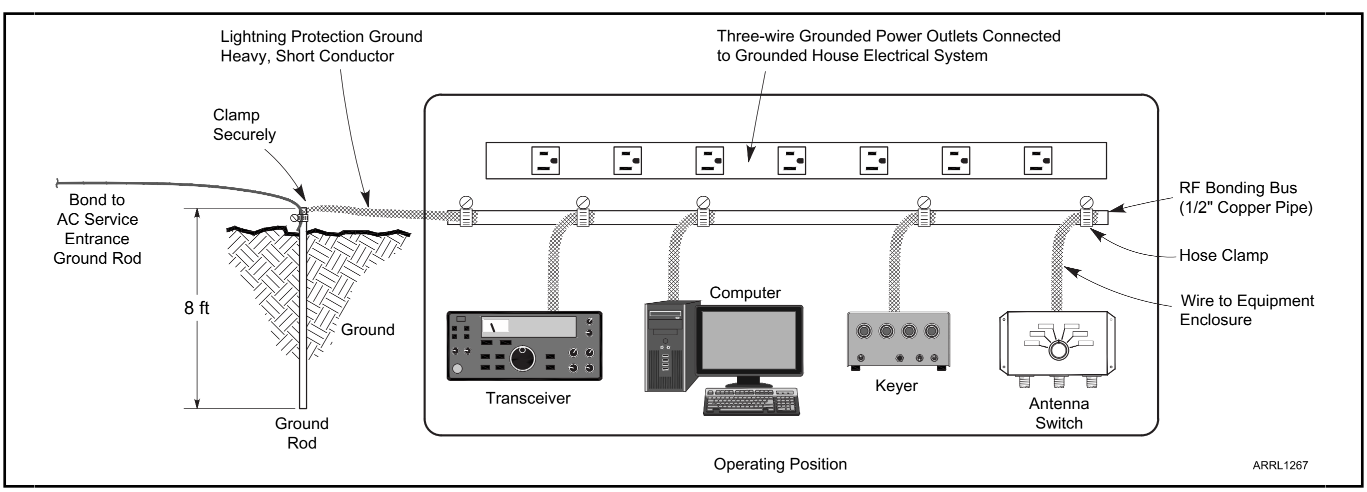


Fig 28.5 — An RF bonding bus connects all of the equipment enclosures together to keep them at the same RF voltage. If the bus is connected to a lightning protection ground, use a heavy conductor, fastened securely. All ground rods must be bonded together and to the residence's ac service entry ground rod. The RF bonding bus should also be connected to the ac safety ground.

the base of a tower, or as part of an overall grounding system. The best ground rods to use are those available from an electrical supply house. The code requires that at least 8 ft of the rod be in contact with the soil, so if the rod sticks out of the ground, it must be longer than 8 ft (10 ft is standard). The rod doesn't have to be vertical, and can be driven at an angle if there is a rock or hard layer, or even buried laying sideways in a suitable trench, although this is a compromise installation. Suitable rods are generally 10 ft long and made from steel with a heavy copper plating. Do not depend on shorter, thinly plated rods sold by some home electronics suppliers, as they can quickly rust and soon become worthless.

If multiple ground rods are installed, they should be spaced by at least half the length of the rod, or the effectiveness is compromised. IEEE Std 142 and IEEE Std 1100 (see the Reference listing) and other references have tables to give effective ground resistances for various configurations of multiple rods.

Once the ground rods are installed, they must be connected with either an exothermic weld (such as CadWeld) or with a listed pressure clamp. The exothermic weld is preferred, because it doesn't require annual inspection like a clamp does. Some installers use brazing to attach the wiring to the ground rods. Although this is not permitted for a primary ground, it is acceptable for secondary or redundant grounds. Soft solder (tin-lead, as used in plumbing or electrical work) should never be used for grounding conductors because it gets brittle with temperature cycling and can melt out if a current surge (as from a lightning strike) heats the conductor. Soft solder is specifically prohibited in the code.

Building cold water supply systems were used as station grounds in years past, but this is no longer recommended or even permitted in some jurisdictions, because of increased used of plastic plumbing both inside and outside houses and concerns about stray currents causing pipe corrosion.. If you do use the cold water line, perhaps because it is an existing grounding electrode, it must be bonded to the electrical system ground, typically at the service entrance panel.

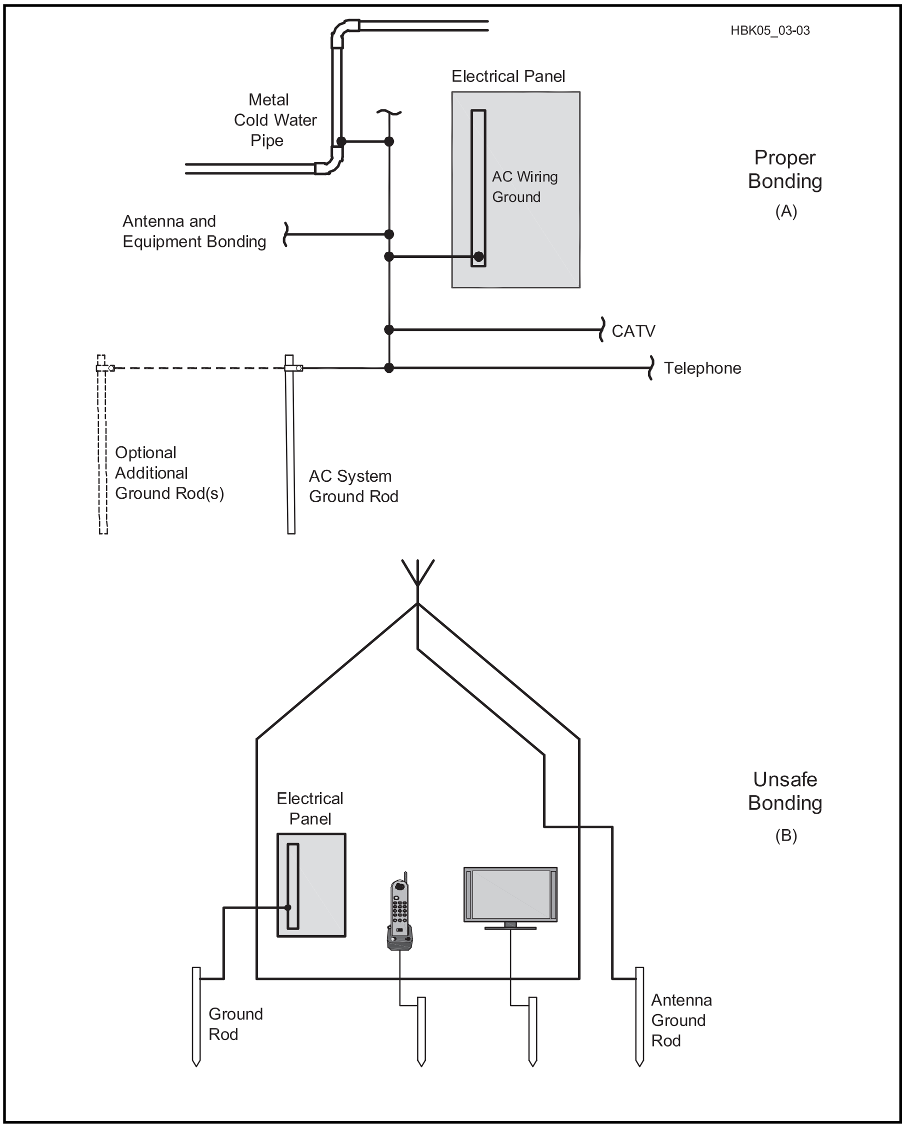


Fig 28.6 — At A, proper bonding of all grounds to electrical service panel. The installation shown at B is unsafe — the separate grounds are not bonded. This could result in a serious accident or electrical fire.

28.1.9 Ground Conductors

The code is quite specific as to the types of conductors that can be used for bonding the various parts of the system together. Grounding conductors may be made from copper, aluminum, copper-clad steel, bronze or similar corrosion-resistant materials. Note that the sizes of the conductors required are based largely on mechanical strength considerations (to insure that the wire isn't broken accidentally) rather than electrical resistance. Insulation is not required. The "protective grounding conductor" (main conductor running to the ground rod) must be as large as the antenna lead-in, but not smaller than #10 AWG. The grounding conductor (used to bond equipment chassis together) must be at least #14 AWG. There is a "unified" grounding electrode requirement — it is necessary to bond *all* grounds to the electric service entrance ground. All utilities, antennas and any separate grounding rods used must be bonded together. **Fig 28.6** shows correct (A) and incorrect (B) ways to bond ground rods. **Fig 28.7** demonstrates the importance of correctly bonding ground rods. (Note: The *NEC* requirements do not address effective RF grounds. See the **RF Interference** chapter of this book for information about RF grounding practices, but keep in mind that RFI is not an acceptable reason to violate the *NEC*.) For additional information on good grounding practices, the IEEE "Emerald Book" (IEEE STD 1100-2005) is a good reference. It is available through libraries.

Additionally, the *NEC* covers safety inside the station. All conductors inside the building must be at least 4 inches away from conductors of any lighting or signaling circuit except when they are separated from other conductors by conduit or insulator. Other code requirements include enclosing transmitters in metal cabinets that are bonded to the grounding system. Of course, conductive handles and knobs must be grounded as well.

28.1.10 Antennas

Article 810 of the *NEC* includes several requirements for wire antennas and feed lines that you should keep in mind when designing your antenna system. The single most

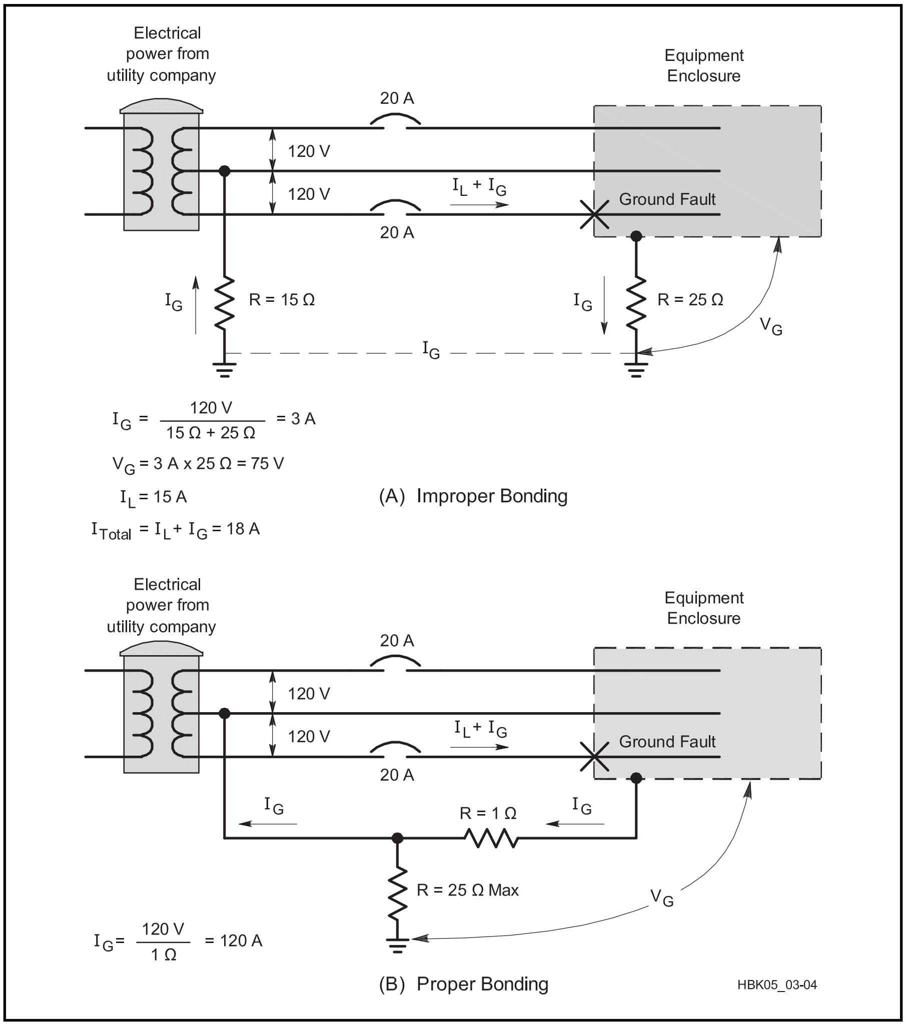


Fig 28.7 — These drawings show the importance of properly bonded ground rods. In the system shown in A, the 20-A breaker will not trip. In the system in B, the 20-A circuit breaker trips instantly. There is an equipment internal short to ground — the ground rod is properly bonded back to the power system ground. Of course, the main protection should be in a circuit ground wire in the equipment power cord itself!

Coax Shields as a Grounding Conductor

The importance of significant current-carrying capability in a grounding conductor is determined by your local circumstances. If lightning is a problem or contact with power-carrying conductors due to wind or ice is a possibility, the ability of the coax shield to carry a lot of current is important and a separate grounding conductor is a good idea. In areas where hazards are reduced, a smaller conductor may suffice. Contact a licensed electrician if you aren't sure about what is prudent for your area.

important thing to consider for safety is to address the potential for contact between the antenna system and power lines. As the code says, "One of the leading causes of electric shock and electrocution, according to statistical reports, is the accidental contact of radio, television, and amateur radio transmitting and receiving antennas and equipment with light or power conductors." (See Article 810.13, Fine Print Note.) The requirements in the code for wire sizes, bonding requirements, and installation practices are mostly aimed at preventing tragedy, by avoiding the contact in the first place, and by mitigating the effects of a contact if it occurs.

Article 820 of the *NEC* applies to Cable TV installations, which almost always use coaxial cable, and which require wiring practices different from Article 810 (for instance, the coax shield can serve as the grounding conductor). Your inspector may look to Article 820 for guidance on a safe installation of coax, since there are many more satellite TV and cable TV installations than Amateur Radio. Ultimately, it is the inspector's call as to whether your installation is safe.

Article 830 applies to Network Powered Communication Systems, and as amateurs do things like install 802.11 wireless LAN equipment at the top of their tower, they'll have to pay attention to the requirements in this Article. The *NEC* requirements discussed in these sections are not adequate for lightning protection and high-voltage transient events. See the section "Lightning/Transient Protection" later in this chapter for more information.

ANTENNA CONDUCTORS

Transmitting antennas should use hard-drawn copper wire: #14 AWG for unsupported spans less than 150 feet, and #10 AWG for longer spans. Copper-clad steel, bronze or other high-strength conductors must be #14 AWG for spans less than 150 feet and #12 AWG for longer spans. Open-wire transmission line conductors must be at least as large as those specified for antennas. Stealth antennas made with light-gauge wire are not code-compliant.

LEAD-INS

There are several *NEC* requirements for antenna lead-in conductors (transmission lines are lead-in conductors). For transmitting stations, their size must be equal to or greater than that of the antenna. Lead-ins attached to buildings must be firmly mounted at least 3 inches clear of the surface of the building on nonabsorbent insulators. Lead-in conductors must enter through rigid, noncombustible, nonabsorbent insulating tubes or bushings, through an opening provided for the purpose that provides a clearance of at least two inches; or through a drilled windowpane. All lead-in conductors to transmitting equipment must be arranged so that accidental contact is difficult. As with stealth antennas, installations with feed lines smaller than RG-58 are likely not code compliant depending on how your local inspector interprets the code.

ANTENNA DISCHARGE UNITS (LIGHTNING ARRESTORS)

All antenna systems are required to have a means of draining static charges from the antenna system. A listed antenna discharge unit (lightning arrestor) must be installed on each lead-in conductor that is not protected by a permanently and effectively grounded metallic shield, unless the antenna itself is permanently and effectively grounded, such as for a shunt-fed vertical. Note that the usual transient protectors are *not* listed antenna discharge units.(The code exception for shielded lead-ins does *not* apply to coax, but to shields such as thin-wall conduit. Coaxial

braid is neither "adequate" nor "effectively grounded" for lightning protection purposes.) An acceptable alternative to lightning arrestor installation is a switch (capable of withstanding many kilovolts) that connects the lead-in to ground when the transmitter is not in use.

ANTENNA BONDING (GROUNDING) CONDUCTORS

In general the code requires that the conductors used to bond the antenna system to ground be at least as big as the antenna conductors, but also at least #10 AWG in size. Note that the antenna grounding conductor rules are different from those for the regular electrical safety bonding, or lightning dissipation grounds, or even for CATV or telephone system grounds.

MOTORIZED CRANK-UP ANTENNA TOWERS

If you are using a motorized crank-up tower, the code has some requirements, particularly if there is a remote control. In general, there has to be a way to positively disconnect power to the motor that is within sight of the motorized device, so that someone working on it can be sure that it won't start moving unexpectedly. From a safety standpoint, as well, you should be able to see or monitor the antenna from the remote control point.

28.1.11 Lightning/Transient Protection

Nearly everyone recognizes the need to protect themselves from lightning. From miles away, the sight and sound of lightning boldly illustrates its destructive potential. Many people don't realize that destructive transients from lightning and other events can reach electronic equipment from many sources, such as outside antennas, power, telephone and cable TV installations. Many hams don't realize that the standard protection scheme of several decades, a ground rod and simple "lightning arrestor" is *not* adequate.

Lightning and transient high-voltage protection follows a familiar communications scenario: identify the unwanted signal, isolate it and dissipate it. The difference here is that the unwanted signal is many megavolts at possibly 200,000 A. What can we do?

Effective lightning protection system design is a complex topic. There are a variety of system tradeoffs which must be made and which determine the type and amount of protection needed. A amateur station in a home is a very different proposition from an air traffic control tower which must be available 24 hours a day, 7 days a week. Hams can easily follow some general guidelines that will protect their stations against high-voltage events that are induced by nearby lightning strikes or that arrive via utility lines. Let's talk about where to find professionals first, and then consider construction guidelines.

Suppliers of Lightning Protection Equipment

For current vendor contact information, use your favorite Internet search tool.

• Alpha Delta Communications: Coax lightning arrestors, coax switches with surge protectors.

• The Wireman: copper wire up to #4 AWG, 2-inch flat copper strap, 8-ft copper clad ground rods and 1 × ¼-inch buss bar.

• ERICO International Corporation: CadWeld bonding system and lightning protection equipment.

• Harger Lightning & Grounding: lightning protection components.

• Industrial Communication Engineers, Ltd (ICE): Coax lightning arrestors.

• PolyPhaser Corporation: Many lightning protection products for feed lines, towers, equipment, and so on.

• Zero Surge Inc: Power line surge protector.

PROFESSIONAL HELP

Start with your local government. Find out what building codes apply in your area and have someone explain the regulations about antenna installation and safety. For more help, look in your telephone yellow pages for professional engineers, lightning protection suppliers and contractors.

Companies that sell lightning-protection products may offer considerable help to apply their products to specific installations. One such source is PolyPhaser Corporation. Look under "References" later in this chapter for a partial list of PolyPhaser's publications.

CONSTRUCTION GUIDELINES

Bonding Conductors

Copper strip (or *flashing*) comes in a number of sizes. The *minimum* recommended grounding conductor for lightning protection is 1.5 inches wide and 0.051 inch thick or #6 AWG stranded wire. Do not use braided strap because the individual strands oxidize over time, greatly reducing the effectiveness of braid as an ac conductor. Bear in mind that copper strap has about the same inductance as a wire of the same length. While strap may be easier to install and provides a lower RF loss (if it's part of a vertical antenna grounding system, for instance), it doesn't provide significant improvement over round wire for power line frequencies (the NEC's concern) or lightning (where inductance dominates the effects).

Use bare copper for buried ground wires. (There are some exceptions; seek an expert's advice if your soil is corrosive.) Exposed runs above ground that are subject to physical damage may require additional protection (a conduit) to meet code requirements. Wire size depends on the application, but never use anything smaller than #6 AWG for bonding conductors. The NEC specifies conductors using wire gauge, and doesn't describe the use of flashing. Local lightning-protection experts or building inspectors can recommend sizes for each application.

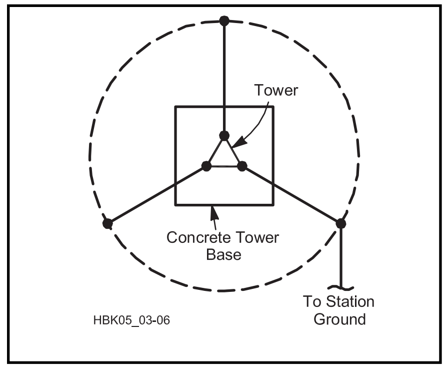


Fig 28.8 — Schematic of a properly grounded tower. A bonding conductor connects each tower leg to a ground rod and a buried (1 foot deep) bare, tinned copper ring (dashed line), which is also connected to the station ground and then to the ac safety ground. Locate ground rods on the ring, as close as possible to their respective tower legs. All connectors should be compatible with the tower and conductor materials to prevent corrosion. See text for conductor sizes and details of lightning and voltage transient protection.

Tower and Antennas

Because a tower is usually the highest metal object on the property, it is the most likely strike target. Proper tower grounding is essential to lightning protection. The goal is to establish short multiple paths to the Earth so that the strike energy is divided and dissipated.

Connect each tower leg and each fan of metal guy wires to a separate ground rod. Space the rods at least 6 ft apart. Bond the leg ground rods together with #6 AWG or larger copper bonding conductor (form a ring around the tower base, see **Fig 28.8**). Connect a continuous bonding conductor between the tower ring ground and the entrance panel. Make all connections with fittings approved for grounding applications. *Do not use solder for these connections.* Solder will be destroyed in the heat of a lightning strike.

Because galvanized steel (which has a zinc coating) reacts with copper when combined with moisture, use stainless steel hardware between the galvanized metal and the copper grounding materials.

Voltage Rise On Wires With Fast Transients

A rule of thumb is that a single wire has an inductance of about 1 µH per meter of length. The voltage across an inductor V= L di/dt. (di/dt is the change in current per unit of time.) A lightning stroke has a rise time of about 1-2 µs, so the current might go from zero to 10 kA in a microsecond or two, a di/dt of over 1 kA/µs (10^9 A/s). An inductance as low as 1 µH would create a voltage of 1000 volts from this current transient.

To prevent strike energy from entering a shack via the feed line, ground the feed line *outside* the home. Ground the coax shield *to the tower* at the antenna and the base to keep the tower and line at the same potential. Several companies offer grounding blocks that make this job easy.

All grounding media at the home must be bonded together. This includes lightning-protection conductors, electrical service, telephone, antenna system grounds and underground metal pipes. Any ground rods used for lightning protection or entrance-panel grounding should be spaced at least 6 feet from each other and the electrical service or other utility grounds and then bonded to the ac system ground as required by the *NEC*.

A Cable Entrance Panel

The basic concept with transient protection is to make sure that all the radio and other equipment is tied together and "moves together" in the presence of a transient voltage. It's not so important that the shack be at "ground" potential, but, rather, that everything is at the *same* potential. For fast rise-time transients such as the individual strokes that make up a lightning strike, even a short wire has enough inductance that the voltage drop along the wire is significant, so whether you are on the ground floor, or the 10th floor of a building, your shack is "far" from Earth potential.

The easiest way to ensure that everything is at the same potential is to tie all the signals to a common reference. In large facilities, this reference would be provided by a grid of large diameter cables under the floor, or by wide copper bars, or even a solid metal floor. A more practical approach for smaller facilities like a ham shack is to have a single "tie point" for all the signals. This is often, but erroneously, called a "single-point ground", but what's really important is not only the shields (grounds) for the signals, but the signal wires as well are referenced to that common potential.

We want to control the flow of the energy in a strike and eliminate any possible paths for surges to enter the building. This involves routing the feed lines, rotator control cables, and so on at least six feet away from other nearby grounded metal objects.

A commonly used approach to ensuring that all the connections are tied together is to route all the signals through a single "entrance panel" which will serve as the "single point ground" although it may not actually be at ground potential. A convenient approach is to use a standard electrical box installed in the exterior wall

Both balanced line and coax arrestors should be mounted to a secure ground connection on the *outside* of the building. The easiest way to do this is to install a large metal enclosure or a metal panel as a bulkhead and grounding block. The panel should be connected to the lightning dissipation ground with a short wide conductor (for minimum impedance), and, like all grounds, bonded to the electrical system's ground. Mount all protective devices, switches and relay disconnects on the outside facing wall of the bulkhead. The enclosure or panel should be installed in a way that if lightning currents cause a component to fail, the molten metal and flaming debris do not start a fire.

Every conductor that enters the structure, including antenna system control lines, should have its own surge suppressor on an entrance panel. Suppressors are available from a number of manufacturers, including Industrial Communication Engineers (ICE) and PolyPhaser, as well as the usual electrical equipment suppliers such as Square-D.

Lightning Arrestors

Feed line lightning arrestors are available for both coax cable and balanced line. Most of the balanced line arrestors use a simple spark gap arrangement, but a balanced line *impulse* suppressor is available from ICE.

DC blocking arrestors for coaxial cable have a fixed frequency range. They present a high-impedance to lightning (less than 1 MHz) while offering a low impedance to RF.

DC continuity arrestors (gas tubes and spark gaps) can be used over a wider frequency range than those that block dc. Where the coax carries supply voltages to remote devices (such as a mast-mounted preamp or remote coax switch), dc-continuous arrestors *must* be used.

28.1.12 Other Hazards in the Shack

UPS AND ALTERNATE ENERGY SOURCES

Many hams have alternate energy sources for their equipment, or an uninterruptible power supply (UPS), so that they can keep operating during a utility power outage. This brings some additional safety concerns, because it means that the "turning off the breaker" approach to make sure that power is disconnected might not work.

In commercial installations, fire regulations or electrical codes often require that the emergency power off (EPO) system (the big red button next to the door) also disconnect the batteries of the UPS system, or at least, disable the ac output. This is so that firefighters who may be chopping holes with conductive tools or spraying conductive water don't face the risk of electrocution. (According to NEC, Articles 645-10 and 645-11, UPSs above 750 VA installed within information technology rooms must be provided with a means to disconnect power to all UPS supply and output circuits. This disconnecting means shall also disconnect the battery from its load. The code further requires that the control for these disconnecting means shall be grouped and identified and shall be readily accessible at the principal exit doors.)

A similar problem exists with solar panel installations. Just because the breaker is turned off doesn't mean that dangerous voltages don't exist on the solar panel. As long as light is falling on them, there is voltage present. With no load, even a relatively dim light falling on part of the panels might present a shock or equipment damage hazard. Modern grid-tie solar systems with no batteries often have the panels wired in series, so several hundred volts is not unusual.

Recent revisions of the *NEC* have addressed many of the aspects of photovoltaic (PV) installations that present problems with disconnects, bonding, and grounding. Consulting your local authorities is always wise, and there are several organizations such as the Southwest Technology Development Institute at New Mexico State University that have prepared useful information (see the references at the end of this section). In general, PV systems at 12 or 24 V aren't covered by the *NEC*.

ENERGIZED CIRCUITS

Working with energized circuits can be very hazardous since, without measuring devices, we can't tell which circuits are live. The first thing we should ask ourselves when faced with troubleshooting, aligning or other "live" procedures is, "Is there a way to reduce the hazard of electrical shock?" Here are some ways of doing just that.

1) If at all possible, troubleshoot with an ohmmeter. With a reliable schematic diagram and careful consideration of how various circuit conditions may reflect resistance readings, it will often be unnecessary to do live testing.

2) Keep a fair distance from energized circuits. What is considered "good practice" in

terms of distance? The *NEC* specifies minimum working space around electric equipment depending on the voltage level. The principle here is that a person doing live work needs adequate space so they are not forced to be dangerously close to energized equipment.

3) If you need to measure the voltage of a circuit, install the voltmeter with the power safely off, back up, and only then energize the circuit. Remove the power before disconnecting the meter.

4) If you are building equipment that has hinged or easily removable covers that could expose someone to an energized circuit, install interlock switches that safely remove power in the event that the enclosure is opened with the power still on. Interlock switches are generally not used if tools are required to open the enclosure.

5) Never assume that a circuit is at zero potential even if the power is switched off and the power cable disconnected. Capacitors can retain a charge for a considerable period of time and may even partially recharge after being discharged. Bleeder resistors should be installed, but don't assume they have discharged the voltage. Instead, after power is removed and disconnected use a "shorting stick" to ground all exposed conductors and terminals to ensure that voltage is not present. If you will be working with charged capacitors that store more than a few joules of energy, you should consider using a "discharging stick" with a high wattage, low value resistor in series to ground that limits the discharge current to around 5-10 A. A dead short across a large charged capacitor can damage the capacitor because of internal thermal and magnetic stress. Avoid using screwdrivers, as this brings the holder too close to the circuit and could ruin the screwdriver's blade. For maximum protection against accidentally energizing equipment, install a shorting lead between high-voltage circuits and ground while you are working on the equipment.

6) Shorting a series string of capacitors does not ensure that the capacitors are discharged. Consider two 400 µF capacitors in series, one charged to +300 V and the other to –300 V with the midpoint at ground. The net voltage across the series string is zero, yet each has significant (and lethal) energy stored in it. The proper practice is to discharge each capacitor in turn, putting a shorting jumper on it after discharge, and then moving to the next one.

7) If you must hold a probe to take a measurement, always keep one hand in your pocket. As mentioned in the sidebar on high-voltage hazards, the worst path current could take through your body is from hand to hand since the flow would pass through the chest cavity.

8) Make sure someone is in the room with you and that they know how to remove the power safely. If they grab you with the power still on they will be shocked as well.

9) Test equipment probes and their leads must be in very good condition and rated for the conditions they will encounter.

10) Be wary of the hazards of "floating" (ungrounded) test equipment. A number of options are available to avoid this hazard.

11) Ground-fault circuit interrupters can offer additional protection for stray currents that flow through the ground on 120-V circuits. Know their limitations. They cannot offer protection for the plate supply voltages in linear amplifiers, for example.

12) Older radio equipment containing ac/dc power supplies have their own hazards. If you are working on these live, use an isolation transformer, as the chassis may be connected directly to the hot or neutral power conductor.

13) Be aware of electrolytic capacitors that might fail if used outside their intended applications.

14) Replace fuses only with those having proper ratings. The rating is not just the current, but also takes into account the speed with which it opens, and whether it is rated for dc or ac. DC fuses are typically rated at lower voltages than those for ac, because the current in ac circuits goes through zero once every half cycle, giving an arc time to quench. Switches and fuses rated for 120 V ac duty are typically not appropriate for high-current dc applications (such as a main battery or solar panel disconnect).

28.1.13 Electrical Safety References

ARRL Technical Information Service Web page on electrical safety in the Technology area of the ARRL website.

Block, R.W., "Lightning Protection for the Amateur Radio Station," Parts 1-3 (Jun, Jul and Aug 2002 *QST*).

Block. R.W., "The "Grounds" for Lightning and EMP Portection," Polyphaser Corporation, 1993.

Federal Information Processing Standards (FIPS) publication 94: *Guideline on Electrical Power for ADP Installations.* FIPS are available from the National Technical Information Service.

IAEI: *Soares' Book on Grounding*, available from International Association of Electrical Inspectors (IAEI).

"IEEE Std 1100 - 2005 IEEE Recommended Practice for Powering and Grounding Electronic Equipment," *IEEE Std 1100-2005 (Revision of IEEE Std 1100-1999)*, pp 0_1-589, 2006. "This document pres-

Electrical Shock Hazards and Effects

What happens when someone receives an electrical shock?

Electrocutions (fatal electric shocks) usually are caused by the heart ceasing to beat in its normal rhythm. This condition, called ventricular fibrillation, causes the heart muscles to quiver and stop working in a coordinated pattern, in turn preventing the heart from pumping blood.

The current flow that results in ventricular fibrillation varies between individuals but may be in the range of 100 mA to 500 mA. At higher current levels the heart may have less tendency to fibrillate but serious damage would be expected. Studies have shown 60-Hz alternating current to be more hazardous than dc currents. Emphasis is placed on application of cardiopulmonary resuscitation (CPR), as this technique can provide mechanical flow of some blood until paramedics can "re-start" the heart's normal beating pattern. Defibrillators actually apply a carefully controlled waveform to "shock" the heart back into a normal heartbeat. It doesn't always work but it's the best procedure available.

What are the most important factors associated with severe shocks?

You may have heard that the current that flows through the body is the most important factor, and this is generally true. The path that current takes through the body affects the outcome to a large degree. While simple application of Ohm's Law tells us that the higher the voltage applied with a fixed resistance, the greater the current that will flow. Most electrical shocks involve skin contact. Skin, with its layer of dead cells and often fatty tissues, is a fair insulator. Nonetheless, as voltage increases the skin will reach a point where it breaks down. Then the lowered resistance of deeper tissues allows a greater current to flow. This is why electrical codes refer to the term "high voltage" as a voltage above 600 V.

How little voltage can be lethal?

This depends entirely on the resistance of the two contact points in the circuit, the internal resistance of the body, and the path the current travels through the body. Historically, reports of fatal shocks suggest that as little as 24 V *could* be fatal under extremely adverse conditions. To add some perspective, one standard used to prevent serious electrical shock in hospital operating rooms limits leakage flow from electronic instruments to only 50 µA due to the use of electrical devices and related conductors inside the patient's body.

ents recommended design, installation, and maintenance practices for electrical power and grounding (including both safety and noise control) and protection of electronic loads such as industrial controllers, computers, and other information technology equipment (ITE) used in commercial and industrial applications."

National Electrical Code, NFPA 70, National Fire Protection Association, Quincy, MA (**www.nfpa.org**).

Solar energy websites — **www.nmsu.edu/~tdi/PV=NEC_HTML/pv-nec/pv-nec.html** and **www.solarabcs.org**

Standard for the Installation of Lightning Protection Systems, NFPA 780, National Fire Protection Association, Quincy, MA (**www.nfpa.org**).

See the Protection Group's list of white papers contained in the Knowledge Base **www.protectiongroup**.com.

28.2 Antenna and Tower Safety

By definition, all of the topics in this book are about radio telecommunications. For those communications, receive and transmit antennas are required and those antennas need to be up in the air to work effectively. While antenna design and construction are covered elsewhere, this section covers many of the topics associated with installing antennas, along with related safety issues.

A substantially more detailed treatment of techniques used to erect towers and antennas is available in these references:

The ARRL Antenna Book

Up the Tower: The Complete Guide to Tower Construction by Steve Morris, K7LXC

Antenna Towers for Radio Amateurs by Don Daso, K4ZA.

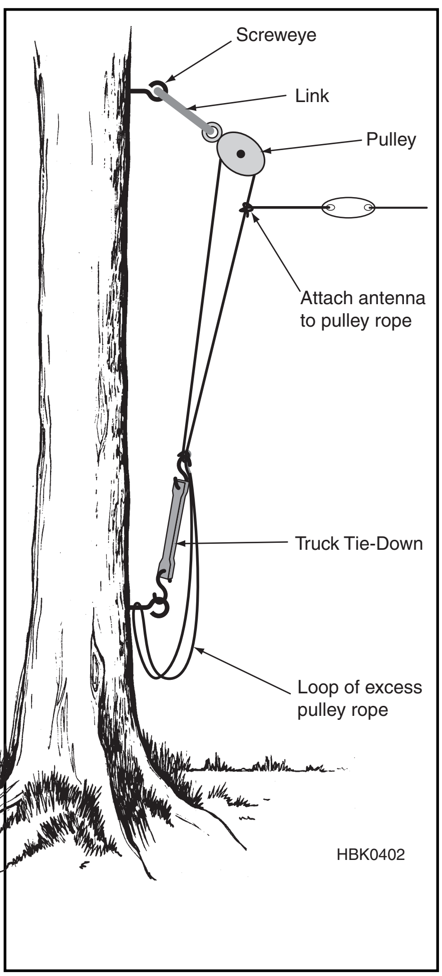


Fig 28.9 — Loop and halyard method of supporting wire antennas in trees. Should the antenna break, the continuous loop of rope allows antenna repair or replacement without climbing the tree.

28.2.1 Legal Considerations

Some antenna support structures fall under local building regulations as well as neighborhood restrictions. Many housing developments have Homeowner's Associations (HOAs) as well as Covenants, Conditions and Restrictions (CC&Rs) that may have a direct bearing on whether a tower or similar structure can be erected at all. This is a broad topic with many pitfalls. Detailed background on these topics is provided in *Antenna Zoning for the Radio Amateur* by Fred Hopengarten, K1VR, an attorney with extensive experience in towers and zoning. You may also want to contact one of the ARRL Field Organization's Volunteer Counsels.

Even without neighborhood issues, a building permit is likely to be required. With the proliferation of cellular and other commercial wireless devices and their attendant RF sites, many local governments now require that the structures meet local building codes. Again, K1VR's book is extremely helpful in sorting all this out. Building permit applications may also require Professional Engineer (PE) calculations and stamp (certification). The ARRL Field Organization's Volunteer Consulting Engineer program may be useful with the engineering side of your project.

28.2.2 Antenna Mounting Structures

TREES AND POLES

The original antenna supports were trees: if you've got them, use them. They're free and unregulated, so it couldn't be easier. Single-trunked varieties such as fir and pine trees are easier to use than the multi-trunked varieties. Multi-trunked trees are not impossible to use — they just require a lot more work. For dipoles or other types of wire antennas, plan for the tree to support an end of the wire; trying to install an inverted V or similar configuration is almost impossible due to all of the intervening branches.

Install an eye-screw with a pulley at the desired height, trim away enough limbs to create a "window" for the antenna through the branches and then attach a rope halyard to the antenna insulator. Here's a useful tip: Make the *halyard* a continuous loop as shown in **Fig 28.9**. Since it's almost always the antenna wire that breaks, a continuous halyard makes it easy to reattach the wire and insulator. With just a single halyard, if the antenna breaks, the tree will have to be climbed to reach the pulley, then reinstall and attach the line. If you're unable to climb the support tree, contact a local tree service. Professional tree climbers are often willing to help out for a small fee.

Another way to get wires into trees is with some sort of launcher. Using a bow-and-arrow is a traditional method of shooting a fishing line over a tree to pull up a bigger line. There are now commercial products available that are easier to use and reach higher in the tree. For example, wrist-rocket slingshots and compressed-air launchers can reach heights of more than 200 feet!

Wooden utility poles offer a tree-related alternative but are not cheap, require special installation with a pole-setting truck, and there is no commercial antenna mounting hardware available for them. That makes them a poor choice for most installations.

TOWERS

The two most important parameters to consider when planning a tower installation are the maximum local *wind speed* and the proposed antenna *wind load*. Check with your local building department to find out what the maximum wind speed is for your area. Another source is a list of maximum wind speeds for all counties in the US from the TIA-222, *Structural Standard for Antenna Supporting Structures and Antennas*. This is an expensive professional publication so it's not for everyone, but the list is posted on the Champion Radio Products website under "Tech Notes." Tower capacities are generally specified in square feet of antenna load and antenna wind load specifications are provided by the antenna manufacturer.

Before beginning, learn and follow K7LXC's Prime Directive of tower construc-

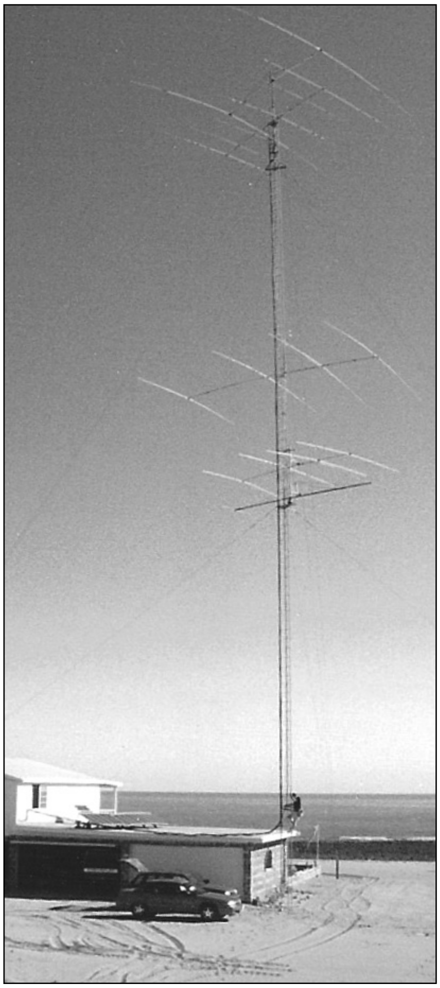


Fig 28.10 — A guyed tower with a good-sized load of antennas at XE2DV-W7ZR in Baja California, is shown at the left. At the right, the Trylon Titan self-supporting tower of W7WVF and N7YYG in Bandon, Oregon. (***K7LXC photos***)

tion — "DO what the manufacturer says." (And DON'T do what the manufacturer doesn't say to do.) Professional engineers have analyzed and calculated the proper specifications and conditions for tower structures and their environment. Taking any shortcuts or making different decisions will result in a less reliable installation.

Towers come in the two varieties shown in **Fig 28.10** — guyed and self-supporting. Guyed towers require a bigger footprint because the guys have to be anchored away from the tower — typically 80% of the tower height. Self-supporting towers need bigger bases to counteract the overturning moment and are more expensive than a guyed tower because there is more steel in them (the cost of a tower is largely determined by the cost of the steel).

The most popular guyed towers are the Rohn 25G and 45G. The 25G is a light-duty tower and the 45G is capable of carrying fairly big loads. The online Rohn catalog (see the References) has most of the information you'll need to plan an installation.

Self-supporting towers are made by several manufacturers and allow building a tower up to 100 feet or higher with a small footprint. Rohn, Trylon and AN Wireless are popular vendors. Another type of self-supporting tower is the *crank-up*, shown in **Fig 28.11**. Using a system of cables, pulleys and winches, crank-up towers can extend from 20 feet to over 100 feet high. These are moderately complex devices. The largest manufacturer of crank-up towers is US Towers.

Fig 28.11 — The bottom of N6TV's crank-up tower is shown at left. The motor drive mechanism is on the left and a fishing net on the right catches and coils the feed lines and control cables as the tower is lowered. On the right, K6KR's fully loaded crank-up extended to its maximum height of 90 feet. (*K7LXC photos*)

Another simple and effective way to get an antenna up in the air is with a *roof-mounted tower*, seen in **Fig 28.12**. These are four-legged aluminum structures of heights from four to more than 20 feet. While they are designed to be lag-screwed directly into the roof trusses, it is often preferable to through-bolt them into a long 2×4 or 2×6 that acts a backing plate, straddling three to four roof trusses. In any case, if it is not clear how best to install the tower on the structure, have a roofing professional or engineer provide advice. Working on a roof-mounted tower also requires extra caution because of climbing on a roof while also working on a tower.

28.2.3 Tower Construction and Erection

THE BASE

Once all the necessary materials and the required approvals have been gathered, tower installation can begin. Let's assume you and your friends are going to install it. The first job is to construct the base. A base for a guyed tower can be hand-dug as can the guy anchors. For a self-supporting tower, renting an excavator of some sort will make it much easier to move the several cubic yards of dirt.

Next, some sort of rebar cage will be needed for the concrete. Guyed towers only require rudimentary rebar while a self-supporting tower will need a bigger, heavier and more elaborate cage. Consult the manufacturer's specifications for the exact materials and dimensions.

Typical tower concrete specs call for 3000 psi (minimum) compressive strength concrete and 28 days for a full cure. A local pre-mix concrete company can deliver it. Pouring the concrete is easiest if the concrete truck can back up to the hole. If that's not possible, a truck- or trailer-mounted line pump can pump it up to 400 feet at minimal expense if using a wheelbarrow is not possible or practical. Packaged concrete from the hardware store mixed manually may also be used. Quikrete Mix #1101 is rated at 2500 psi after seven days and 4000 psi after 28 days.

Principles of Working Safely

The following safety tenets are adapted to amateur antenna system and tower work from selected items of the Chevron Tenets of Operation. These are founded on three fundamental principles: Do it safely or not at all; There's always time to do it right; and If it's worth doing, do it better.

1. Never load or operate structures or equipment outside the design limits. Be careful with tools, ropes, pulleys, and other equipment that can cause injury or damage if they fail due to overload. Use the right stuff!
2. Always move to a safe, controlled condition and seek assistance when a situation is not understood. This is particularly important when working on towers and antennas. If something doesn't look right or isn't going according to plan, return to a safe state and figure out what to do.
3. Always operate with the safety mechanisms engaged. If a safety mechanism prevents you from doing something, either the task is unsafe or you may not be using the right equipment.
4. Always follow safe work practices and procedures. Make a plan before you start and don't do something you know is unsafe.
5. Act to stop unsafe practices. The team's safety depends on every team member. Do not hesitate to stop work if you see it is unsafe. Don't be afraid to speak up or ask for help! Regroup and do it right.
6. Clarify and understand procedures before proceeding. This is particularly important when working with a crew. Be sure everyone understands the procedure and how to communicate.
7. Involve people with expertise and firsthand knowledge in decisions and planning. Ask for advice and guidance from experienced hams when planning a task with which you are unfamiliar.

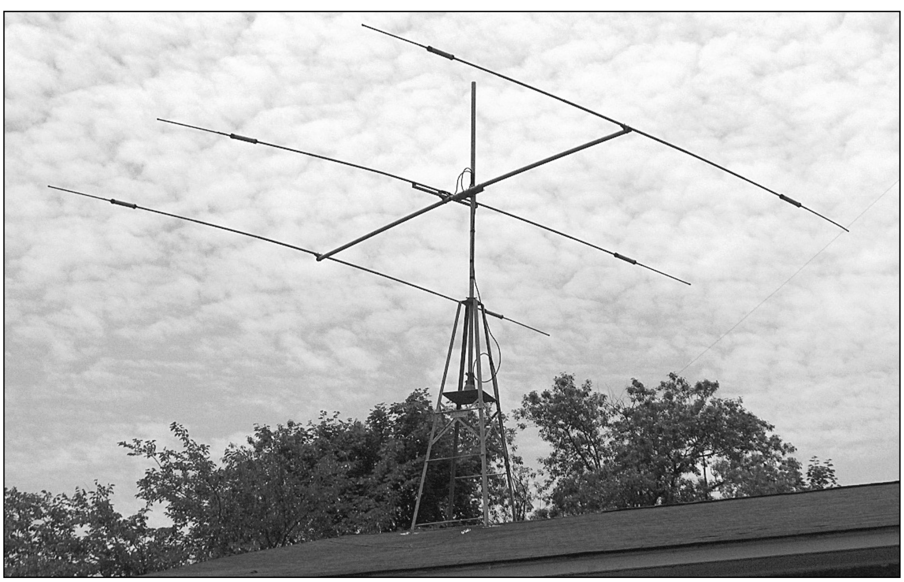


Fig 28.12 — The roof-mounted tower holding the AA2OW antenna system. (*AA2OW photo*)

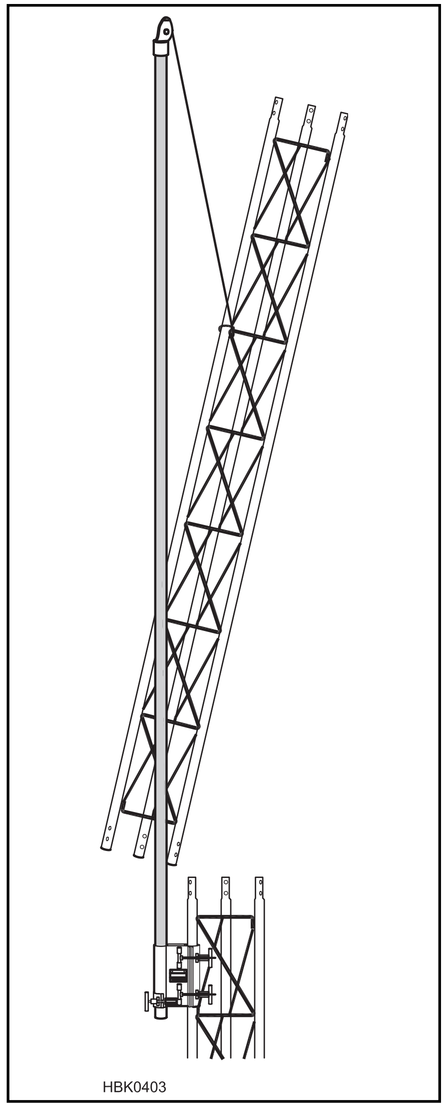
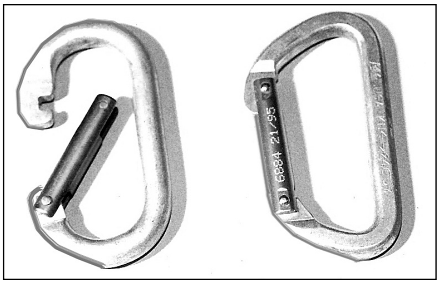
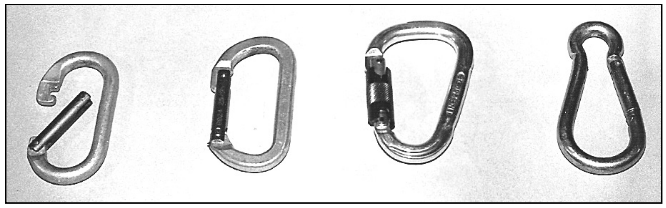


Fig 28.13 — A gin-pole consists of a leg clamp fixture, a section of aluminum mast and a pulley. It is used to lift the tower section high enough to be safely lowered into place and attached. (Based on Rohn EF2545.)



(A)



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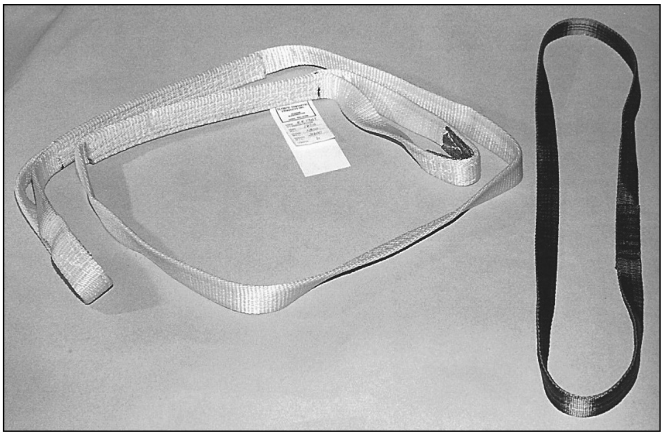

(C)

Fig 28.14 — (A) Oval mountain climbing type carabiners are ideal for tower workloads and attachments. The gates are spring loaded — the open gate is shown for illustration. (B) An open aluminum oval cara-biner; a closed oval carabiner; an aluminum locking carabiner; a steel snaplink. (C) A heavy duty nylon sling on the left for big jobs and a lighter-duty loop sling on the right for everything else. (*K7LXC photos*)

TOOLS

Once the base and anchors are finished and the concrete has cured, the tower can be constructed. There are several tools that will make the job easier. If the tower is a guyed tower, it can be erected either with a crane or a *gin-pole*. The gin-pole, shown in **Fig 28.13**, is a pipe that attaches to the leg of the tower and has a pulley at the top for the haul rope. Use the gin-pole to pull up one section at a time (see below).

Another useful tool for rigging and hoisting is the *carabiner*. Shown in **Fig 28.14** (A and B), carabiners are oval steel or aluminum snap-links popularized by mountain climbers. They have spring-loaded gates and can be used for many tower tasks. For instance, there should be one at the end of the haul rope for easy and quick attachment to rotators, parts and tool buckets — virtually anything that needs to be raised or lowered. It can even act as a "third hand" on the tower.

Along with the carabineer, the *nylon loop sling* in Fig 28.14C can be wrapped around large or irregularly shaped objects such as antennas, masts or rotators and attached to ropes with carabiners. For a complex job, a professional will often climb with eight to ten slings and use every one!

A pulley or two will also make the job easier. At a minimum, one is needed for the haul rope at the top of the tower. A *snatch block* is also useful; this is a pulley whose top opens up to "snatch" (attach it to) the rope at any point. **Fig 28.15** shows two snatch-block pulleys used for tower work.

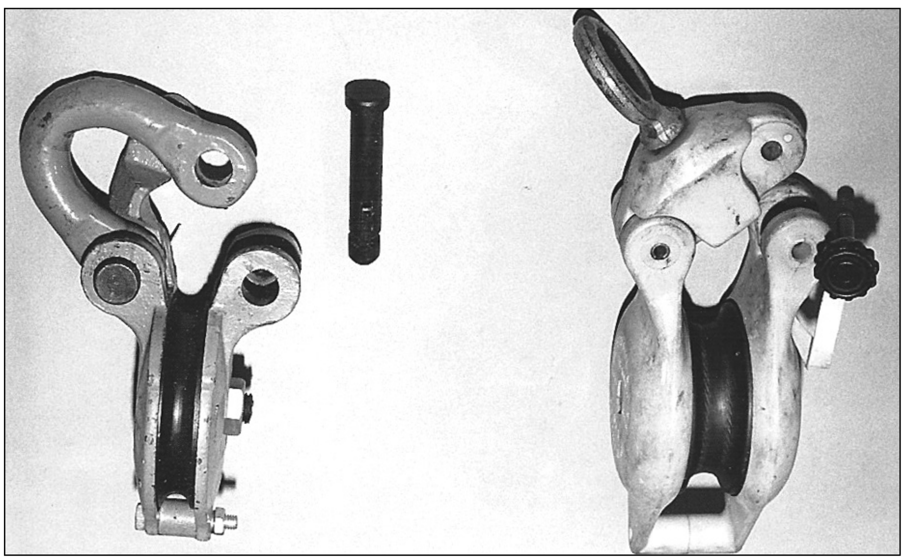

Fig 28.15 — Two snatch blocks; a steel version on the left and a lightweight high impact plastic one on the right in their open position. (*K7LXC photo*)

ROPES

Speaking of ropes, use a decent haul rope. Rope that is one-half inch diameter or larger affords a good grip for lifting and pulling. There are several choices of rope material. The best choice is a synthetic material such as nylon or Dacron. A typical twisted rope is fine for most applications. A synthetic rope with a braid over the twisted core is known as *braid-on-braid* or *kernmantle*. While it's more expensive than twisted ropes, the outer braid provides better abrasion resistance. The least expensive type of rope is polypropylene. It's a stiff rope that doesn't take a knot as well as other types but is reasonably durable and cheap. **Table 28.2** shows the safe working load ratings for common types of rope.

When doing tower work, being able to tie knots is required. Of all the knots, the *bowline* is the one to know for tower work. The old "rabbit comes up through the hole, around the tree and back down the hole" is the most familiar method of tying a bowline. Most amateurs are knot-challenged so it's a great

advantage to know at least this one.

INSTALLING TOWER SECTIONS

The easiest way to erect a tower is to use a crane. It's fast and safe but more expensive than doing it in sections by hand. To erect a tower by sections, a gin-pole is needed (see Fig 28.13). It consists of two pieces — a clamp or some device to attach it to the tower leg and a pole with a pulley at the top. The pole is typically longer than the work piece being hoisted, allowing it to be held above the tower top while being attached or manipulated.

With the gin-pole mounted on the tower, the haul rope runs up from the ground, through the gin-pole mast and pulley at the top of the gin-pole, and back down the tower. The haul rope has a knot (preferably a bowline) on the end for attaching things to be hauled up or down. A carabiner hooked into the bight of the knot can be attached to objects quickly so that you don't have to untie and re-tie the bowline with every use.

It's a good idea to pass the haul rope through a snatch-block at the bottom of the tower. This changes the direction of the rope from vertical to horizontal, allowing the ground crew to stand away from the tower (and the fall zone for things dropped off the tower) to manipulate the haul rope while also watching what's going on up on the tower.

GUYS

For guyed towers, an important construction parameter is guy wire material and *guy tension*. Do *not* use rope or any other material not rated for use as guy cable as permanent tower guys. Guyed towers for amateurs typically use either 3⁄16-inch or ¼-inch *EHS* (extra high strength) steel guy cable. The only other acceptable guy material is Phillystran — a lightweight cable made of Kevlar fibers. Phillystran is available witht he same breaking strength as EHS cable. The advantage of Phillystran is that it is non-conducting and does not create unwanted electrical interaction with antennas on the tower. It is an excellent choice for towers supporting multiple Yagi and wire antennas and does not have to be broken up into short lengths with insulators.

EHS wire is very stiff — to cut it, use a hand-grinder with thin cutting blades or a circular saw with a pipe-cutting aggregate blade. Be sure to wear safety glasses and gloves when cutting since there will be lots of sparks of burning steel being thrown off. Phillystran can be cut with a utility knife or a hot knife for cutting plastic.

If the guys are too loose, the result will be wind-induced shock loading. Guys that are too tight exert extra compressive load on the tower legs, reducing the overall capacity and reliability of the tower. The proper tension of EHS or Phillystran guys is 10% of the material's *ultimate breaking strength*. For 3⁄16-inch EHS the ultimate breaking strength is 4900 pounds and for ¼-inch it's 6000 pounds so the respective guy tension should be 490 pounds and 600 pounds. The easiest to use, most accurate, and least expensive way to measure guy tension is by using a Loos tension gauge. It was developed for sailboat rigging so it's available at some marine supply stores or from Champion Radio Products.

Guy wires used to be terminated in a loop with cable clamps but those have been largely replaced by pre-formed Big Grips, shown in **Fig 28.16**. These simply twist onto the guy wire and are very secure. They grip the guy cable by squeezing the cable as tension is applied. Be sure to use the right type of Big Grips for the thickness and material of the guy cable.

Table 28.2
Rope Sizes and Safe Working Load Ratings in Pounds

3 Strand Twisted Line

Diameter	*Manila*	*Nylon*	*Dacron*	*Polypropylene*
¼	120	180	180	210
⅜	215	405	405	455
½	420	700	700	710
⅝	700	1140	1100	1050

Double-Braided Line

Diameter	*Nylon*	*Dacron*
¼	420	350
⅜	960	750
½	1630	1400
⅝	2800	2400

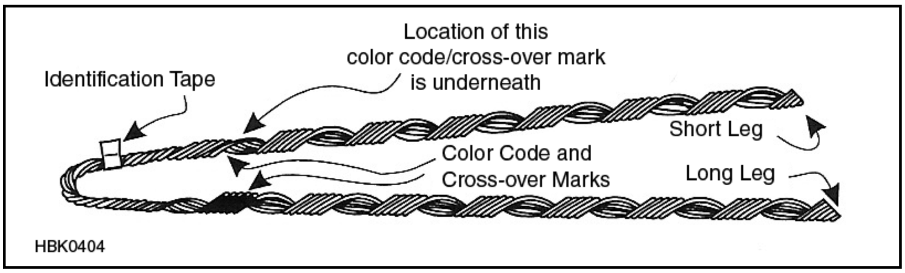

Fig 28.16 — A PreFormed Line Products Big Grip for guy wires.

Table 28.3
Yield Strengths of Mast Materials

Material	*Specification*	*Yield Strength (lb/in.²)*
Drawn aluminum tube	6063-T5	15,000
	6063-T832	35,000
	6061-T6	35,000
	6063-T835	40,000
	2024-T3	42,000
Aluminum pipe	6063-T6	25,000
	6061-T6	35,000
Extruded alum. tube	7075-T6	70,000
Aluminum sheet and plate	3003-H14	17,000
	5052-H32	22,000
	6061-T6	35,000
Structural steel	A36	33,000
Carbon steel, cold drawn	1016	50,000
	1022	58,000
	1027	70,000
	1041	87,000
	1144	90,000
Alloy steel	2330 cold drawn	119,000
	4130 cold worked	75,000
	4340 1550 °F quench 1000 °F temper	162,000
Stainless steel	AISI 405 cold worked	70,000
	AISI 440C heat-treated	275,000

(From *Physical Design of Yagi Antennas* by David B. Leeson, W6NL)

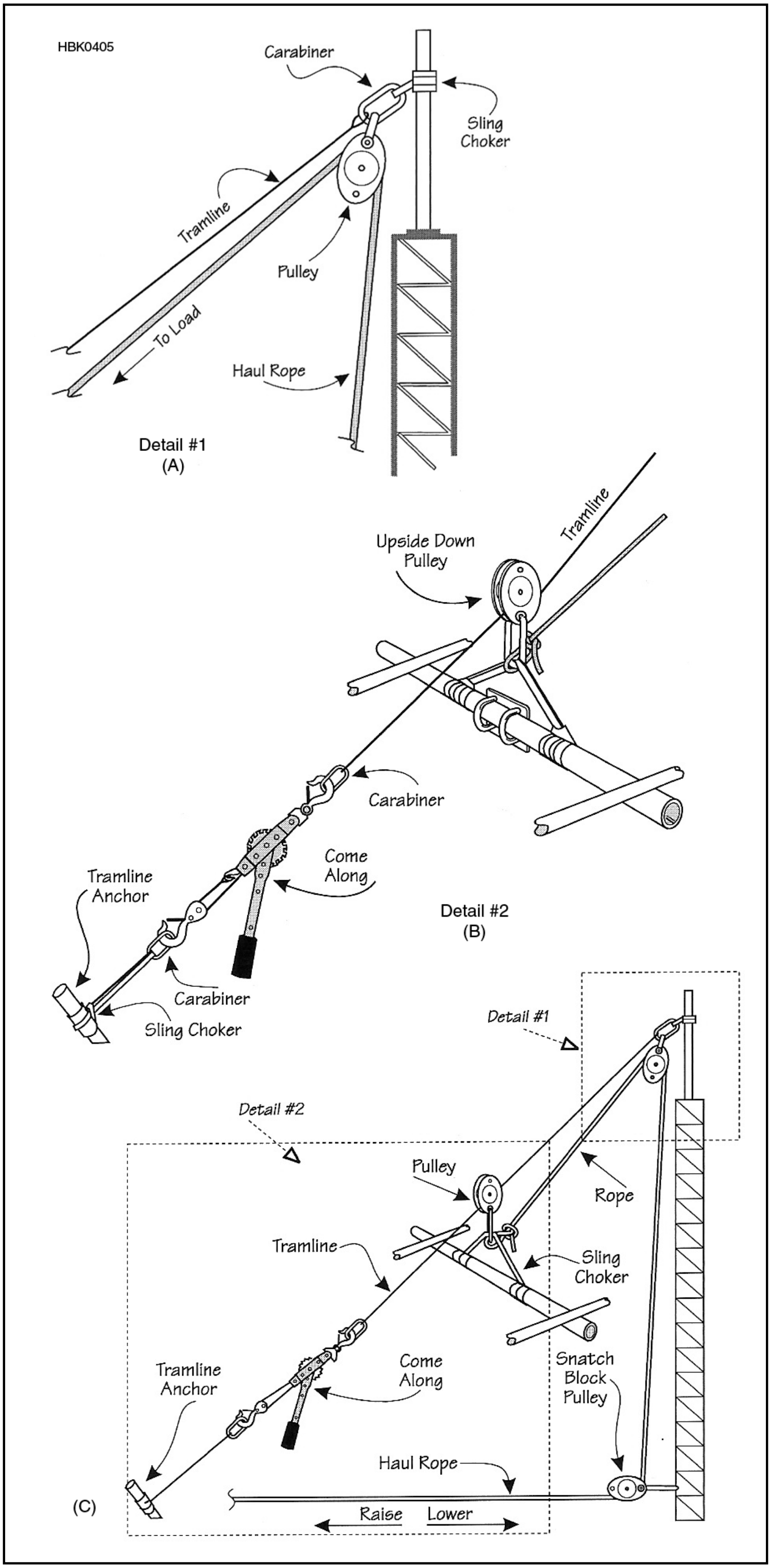

Fig 28.17 — At A, rigging the top of the tower for tramming antennas. Note the use of a sling and carabiner. (B) Rigging the anchor of the tramline. A come-along is used to tension the tramline. (C) The tram system for getting antennas up and down. Run the antenna part way up the tramline for testing before installation. It just takes a couple of minutes to run an antenna up or down once the tramline is rigged.

28.2.4 Antenna Installation

Now that the tower is up, install the antennas. VHF/UHF whips and wire antennas are pretty straightforward, but installing an HF Yagi is a more challenging proposition. With a self-supporting tower, there are no guy wires to contend with — generally, the antenna can just be hauled up the tower face. Sometimes it is that easy!

In most cases, short of hiring a crane, the easiest way to get a Yagi up and down a tower is to use the *tram* method. A single tramline is suspended from the tower to the ground and the load is suspended under the tramline. Another technique is the *trolley* method in which two lines are suspended from the tower to the ground and the antenna rides on top of the lines like a trolley car on tracks. Problems with the trolley technique include trying to get the lines to have the same tension, balancing the antenna so that it won't fall off of the lines, and the added friction of pulling the antenna up two lines. The tram method has none of these problems. **Fig 28.17** illustrates the tram method of raising antennas.

Tram and trolley lines are typically attached to the mast above the top of the tower. In the case of a big load, the lines may exert enough force to bend the mast. If in doubt, *back-guy* the mast with another line in the opposite direction for added support.

MASTS

A mast is a pipe that sticks out of the top of the tower and connects the rotator to the antenna. For small antenna loads and moderate wind speeds, any pipe will work. But as wind speed and wind load increase, more force will be exerted on the mast.

There are two materials used for masts — *pipe* and *tubing*. Pipe can be water pipe or conduit (EMT). Pipe is a heavy material with not much strength since its job is just to carry water or wires. Pipe is acceptable as mast material for small loads only. Another problem is that 1.5-in. pipe (pipe is measured by its inside diameter or ID) is only 1.9-in. OD. Since most antenna boom-to-mast hardware is designed for a 2-in. mast, the less-than-perfect fit may lead to slippage.

For any larger load use carbon-alloy steel tubing rated for high strength. A moderate antenna installation in an 80 MPH wind might exert 40,000 to 50,000 pounds per square inch (psi) on the mast. Pipe has a yield strength

of about 35,000 psi, so you can see that pipe is not adequately rated for this type of use. Chromoly steel tubing is available with yield strengths from 40,000 psi up to 115,000 psi but it is expensive. **Table 28.3** shows the ratings of several materials used as masts for amateur radio antennas.

Calculating the required mast strength can be done by using a software program such as the *Mast, Antenna and Rotator Calculator (MARC)* software. (See the References.) The software requires as inputs the local wind speed, antenna wind load, and placement on the mast. The software then calculates the mast bending moment and will recommend a suitable mast material.

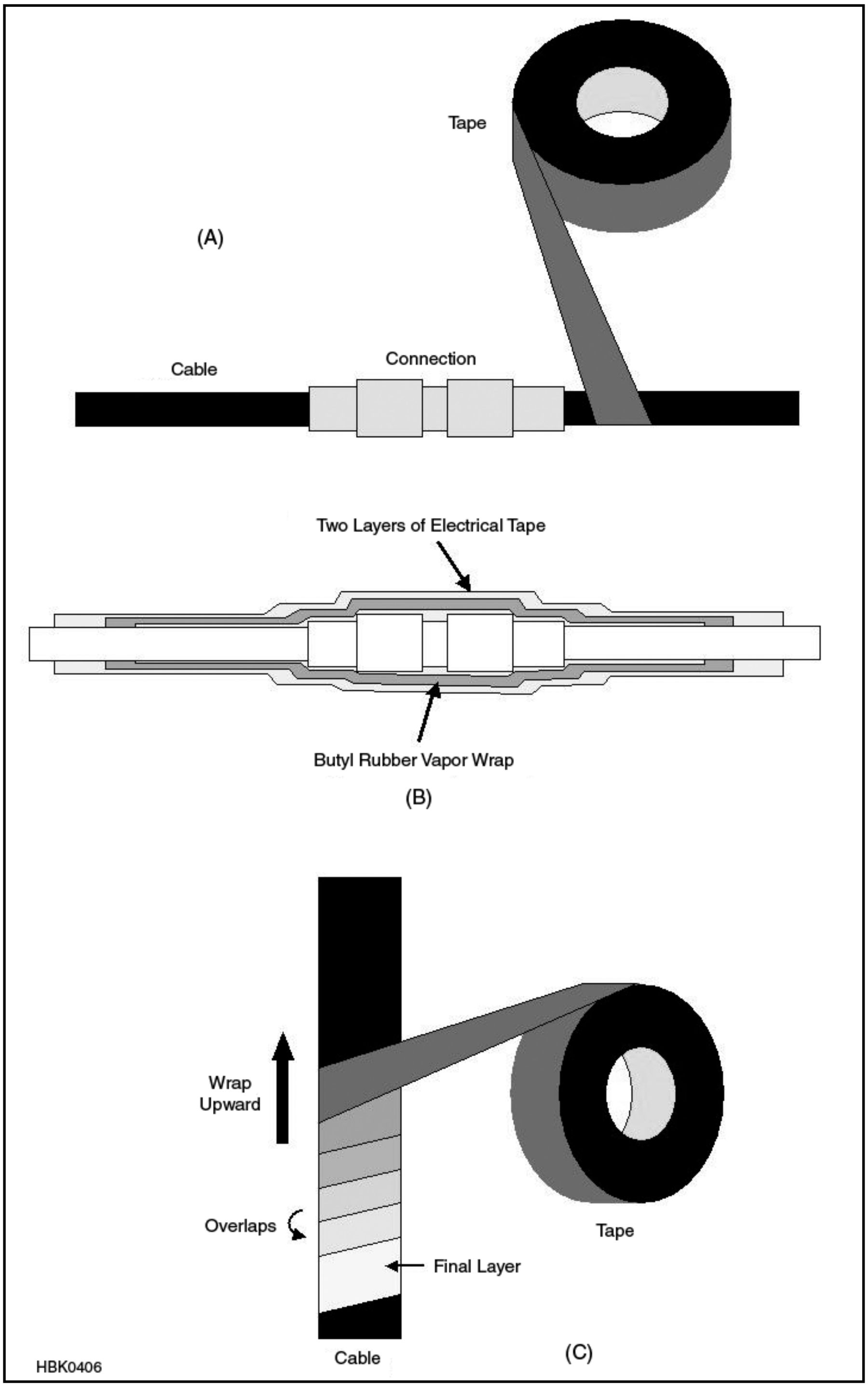

Fig 28.18 — Waterproofing a connector in three steps. At A, cover the connectors with a layer of good-quality electrical tape. B shows a layer of butyl rubber vapor wrap between the two layers of electrical tape. C shows how to wrap tape on a vertical cable so that the tape sheds water away from the connection. (Drawing (C) reprinted courtesy of *Circuitbuilding for Dummies*, Wiley Press)

28.2.5 Weatherproofing Cable and Connectors

The biggest mistake amateurs make with coaxial cable is improper weatherproofing. (Coax selection is covered in the chapter on **Transmission Lines**.) **Fig 28.18** shows how to do it properly. First, use high-quality electrical tape, such as 3M Scotch 33+ or Scotch 88. Avoid inexpensive utility tape. After tightening the connector (use pliers carefully to seat threaded connectors — hand-tight isn't good enough), apply two wraps of tape around the joint.

When you're done, sever the tape with a knife or tear it very carefully — *do not* stretch the tape until it breaks. This invariably leads to "flagging" in which the end of the tape loosens and blows around in the wind. Let the tape relax before finishing the wrap.

Next put a layer of butyl rubber *vapor wrap* over the joint. (This tape is also available in the electrical section of the hardware store.) Finally, add two more layers of tape over the vapor wrap, creating a professional-quality joint that will never leak. Finally, if the coax is vertical, be sure to wrap the final layer so that the tape is going *up* the cable as shown in Fig 28.18. In that way, the layers will act like roofing shingles, shedding water off the connection. Wrapping it top to bottom will guide water between the layers of tape.

28.2.6 Climbing Safety

Tower climbing is a potentially dangerous activity, so you'll need to use the proper safety equipment and techniques. OSHA, the Federal Occupational Safety and Health Administration, publishes rules for workplace safety. Although amateurs are not bound by those rules, you'll be much better off by following them. What equipment and techniques you use are up to you. As long as you've got the right safety equipment and follow the basic safety rules you won't have any problems.

SAFETY AWARENESS AND PREPARATION

One of the most important aspects of safety is having the knowledge and awareness to do a job safely and efficiently. You must have the mental ability to climb and work at altitude while constantly rethinking all connections, techniques and safety factors. Safely climbing and working on towers is 90% mental. Mental preparedness is something that must be learned. This is an occasion where there is no substitute for experience. The biggest obstacle for anyone is making the mental adjustment. Properly installed towers are inherently safe and accidents are relatively rare.

You should also check your safety equipment every time before you use it.

Inspect it for any nicks or cuts to your belt and safety strap. Professional tower workers are required to check their safety equipment every day and you should check yours before each use.

One of the most important lessons for tower climbing is that you have four points of attachment and security — two hands and two feet. When climbing, move only one point at a time. That leaves you with three points of contact and a wide margin of safety if you ever need it. This is in addition to having your fall-arrest lanyard (see below) connected at all times.

Another recommended technique is to always do everything the same way every time. That is, always wear your positioning lanyard on the same D-ring and always connect it in the same way. Always look at your belt D-ring while clipping in with your safety strap. This way you'll always confirm that you're securely belted in. Always look!

PERSONAL SAFETY EQUIPMENT

The most important pieces of safety equipment are the *fall arrest harness* (FAH) you wear and the accompanying lanyards that attach to it (**Fig 28.19**). The FAH has leg loops and suspenders to help spread the fall forces over more of your body and has the ability to hold you in a natural position with your arms and legs hanging below you where you're able to breathe normally.

Two or more lanyards are used. One is the positioning lanyard (**Fig 28.20**). That is, it holds you in working position and attaches to the D-rings at your waist. They can be adjustable or fixed and are made from different materials such as nylon rope, steel chain or special synthetic materials. An adjustable positioning lanyard will adjust to almost any situation whereas a fixed-length one is typically either too long or too short. A rope lanyard is the least expensive.

Leather safety equipment was outlawed

(A)

(B)

Fig 28.19 — (A) The well-dressed tower climber. Note the waist D-rings for positioning lanyard attachment as well as the suspenders and leg loops. At (B) is an adjustable positioning lanyard. The climber also has working boots, gloves, safety glasses and hardhat. (*K7LXC photos*)

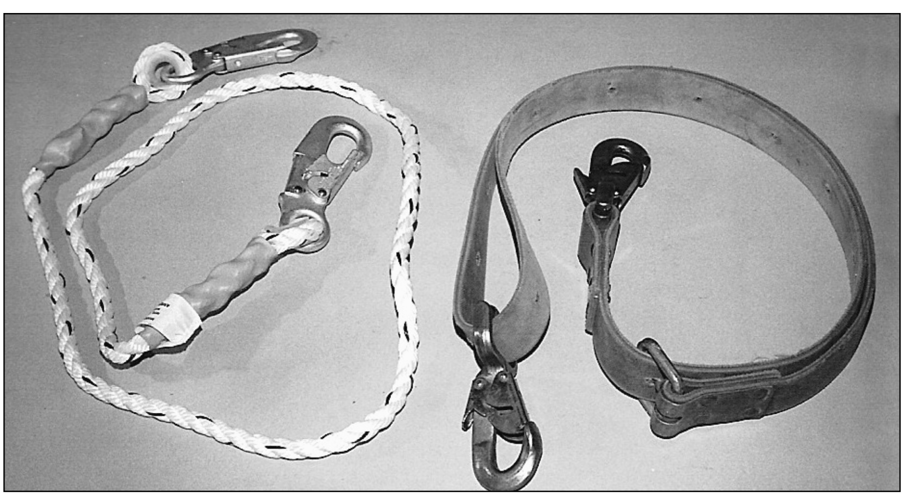

Fig 28.20 — A fixed-length rope positioning lanyard on the left and a versatile adjustable lanyard on the right. (*K7LXC photos*)

Fig 28.21 — The fall-arrest lanyard is above the climber so that the climber can climb up to it. The fall-arrest and positioning lanyards are then "leapfrogged" so that the climber remains attached to the tower 100 percent of the time. (*K7LXC photos*)

some years ago by OSHA so don't use it. This includes the old-fashioned safety belt that was used for years but offers no fall arrest capability. If you drop down while wearing a safety belt, your body weight can cause it to rise up from your waist to your ribcage where it will immobilize your diaphragm and suffocate you. On the other hand you can use a safety belt for positioning when it's worn over an FAH. Just don't depend on it to catch you in case of a fall.

The other lanyard is the fall arrest lanyard, shown in **Fig 28.21**, which attaches to a D-ring between your shoulder blades. The other end attaches to the tower above the work position and catches you in case of a fall. The simplest is a 6 foot rope lanyard which is inexpensive but doesn't offer any shock absorption. There are also shock absorbing varieties that typically have bar-tacked stitches that pull apart under force to decelerate you. Don't cut corners on buying or using safety equipment; you bet your life on it every time you use it!

OSHA rules and good common sense say you should be attached to the tower 100% of the time. You can do this several ways. One is to attach the fall arrest lanyard above you and climb up to it. Use your positioning lanyard to hold you while you detach it and move it up again. Repeat as necessary. Another option is to use a pair of fall arrest lanyards, attaching one then the other as you climb the tower.

Boots should be leather with a steel or fiberglass shank. Diagonal bracing on Rohn 25G is only 5⁄16 inch rod — spending all day standing on that small step will take a toll on your feet. The stiff shank will support your weight and protect your feet; tennis shoes will not. Leather boots are mandatory on towers like Rohn BX that have sharp X-cross braces. Your feet are always on a slant and that is hard on feet.

A hard hat and safety goggles is highly recommended. Just make sure they are ANSI or OSHA approved and that you and your crew wear them. As you'll be looking up and down a lot, a chin strap is essential to keep the hard hat from falling off.

If you do a lot of tower work, your hands will take a beating. Gloves are essential — keep several spare pair for ground crew members who show up without them. Cotton gloves are fine for gardening but not for tower work; they don't provide enough friction for climbing or working with a haul rope. Leather gloves are the only kind to use; either full leather or leather-palmed are fine. The softer the gloves the more useful they'll be. Stiff leather construction gloves are fine for the ground crew but pigskin and other soft leathers are better for the climber because you can thread a nut or do just about any other delicate job with these gloves on.

Safety Tips

1) Don't climb with anything in your hands; attach it to your safety belt if you must climb with it or have your ground crew send it up to you in a bucket.

2) Don't put any hardware in your mouth; it can easily be swallowed.

3) Remove any rings and/or neck chains; they can get hooked on things.

4) Be on the lookout for bees, wasps and their nests. If you do run into a hornet, wasp or other stinging insect, use Adolph's Meat Tenderizer on the sting — it contains the enzyme papain which neutralizes the venom. Have a small jar in your tool kit.

5) Don't climb when tired; that's when most accidents occur.

6) Don't try to lift anything by yourself; one person on a tower has very little leverage or strength. Let the ground crew use their strength; save yours for when you really need it.

7) If a procedure doesn't work, assess the situation and re-rig, if necessary, before trying again.

GROUND CREW SAFETY

The climber on the tower is the boss. Before tower work starts, have a safety meeting with the ground crew. Explain what is going to be done and how to do it as well as introducing them to any piece of hardware with which they may not be familiar (for example, carabiners, slings or come-along winches).

As part of the ground crew, there are a few rules to follow:

1) The climber on the tower is in charge.

2) Don't do anything unless directed by the climber in charge on the tower. This includes handling ropes, tidying up, moving hardware, and so on.

3) If not using radios to communicate, when talking to the climber on the tower, look up and talk directly to him or her in a loud voice. The ambient noise level is higher up on the tower because of traffic, wind and nearby equipment.

4) Communicate with the climber on the tower. Let him or her know when you're ready or if you're standing by or if there is a delay. Advise the climber when lunch is ready!

28.2.7 Antenna and Tower Safety References

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28.3 RF Safety

Amateur Radio is basically a safe activity. In recent years, however, there has been considerable discussion and concern about the possible hazards of electromagnetic fields (EMF), including both RF energy and power frequency (50-60 Hz) EMF. FCC regulations set limits on the maximum permissible exposure (MPE) allowed from the operation of radio transmitters. Following these regulations, along with the use of good RF practices, will make your station as safe as possible. This section, written by the ARRL RF Safety Committee (see sidebar), deals with the topic of electromagnetic safety.

28.3.1 How EMF Affects Mammalian Tissue

All life on Earth has adapted to live in an environment of weak, natural, low frequency electromagnetic fields, in addition to the Earth's static geomagnetic field. Natural low-frequency EM fields come from two main sources: the sun and thunderstorm activity. During the past 100 years, man-made fields at much higher intensities and with different spectral distributions have altered our EM background. Researchers continue to look at the effects of RF exposure over a wide range of frequencies and levels.

Both RF and power frequency fields are classified as *nonionizing radiation* because the frequency is too low for there to be enough photon energy to ionize atoms. *Ionizing radiation*, such as X-rays, gamma rays and some ultraviolet radiation, has enough energy to knock electrons loose from atoms. When this happens, positive and negative *ions* are formed. Still, at sufficiently high power densities, nonionizing EMF poses certain health hazards.

It has been known since the early days of radio that RF energy can cause injuries by heating body tissue. Anyone who has ever touched an improperly grounded radio chassis or energized antenna and received an *RF burn* will agree that this type of injury can be quite painful. Excessive RF heating of the male reproductive organs can cause sterility by damaging sperm. Other health problems also can result from RF heating. These heat related health hazards are called *thermal effects*. A microwave oven is an application that puts thermal effects to practical use.

There also have been observations of changes in physiological function in the presence of RF energy levels that are too low to cause heating. These functions generally return to normal when the field is removed. Although research is ongoing, no harmful health consequences have been linked to these changes.

In addition to the ongoing research, much else has been done to address this issue. For example, FCC regulations set limits on exposure from radio transmitters. The Institute of Electrical and Electronics Engineers, the American National Standards Institute and the National Council for Radiation Protection and Measurement, among others, have recommended voluntary guidelines to limit human exposure to RF energy. The ARRL maintains an RF Safety Committee, consisting of concerned scientists and medical doctors, who volunteer to serve the radio amateur community to monitor scientific research and to recommend safe practices.

The ARRL RF Safety Committee

Imagine you wake up one day and the newspaper headlines are screaming that scientists have discovered radio waves cause cancer. How would you react? How would your neighbor react? You may not have to imagine very hard because the news has been inundated with this type of story regularly over the past couple of decades. Clearly our society has not been decimated by epidemics of diseases since the vast increase in cellular telephone use. Some people deal with this discrepancy by ignoring all scientific reports. Others adopt a pessimistic attitude that technology is going to kill us all eventually, while still others treat every such story as “the truth” and militantly try to stop the transmission of RF energy. The reality is that while all scientific study is complex, the study of electromagnetic biological effects is even more so. Few newspaper reporters are capable of understanding the nuances of a scientific study and are even less able to properly report its results to the lay public. As a result many newspaper stories mislead the public into thinking that a scientific study has found something about which they need to be warned.

The ARRL has dealt with this dilemma by creating the RF Safety Committee, a group of experts in the facets of medical, scientific and engineering investigation needed to fully critique and understand the results of studies on electromagnetic biological effects. Experts in Dosimetry, Public Health, Epidemiology, Statistical Methods, General Medicine and specific diseases are well suited to reading and understanding published scientific reports and critiquing their validity.

It is not uncommon to examine how an experiment was performed only to realize that errors were made in the design of the experiment or the interpretation of its results. It takes a group of reviewers with a wide range of expertise to consider the implications of all aspects of the study to recognize the value of the results.

The field of biological effects of electromagnetic energy constitutes a complex combination of scientific disciplines. Many scientific studies in this field do not generate reliable results because they are not based on input from experts in the many fields that affect the interactions between electromagnetic energy and biological organisms. Even well designed scientific studies are subject to misinterpretation when the results are presented to a public that does not understand or appreciate the complex interactions that occur between the physical world and biological organisms and how these affect public health.

Since the 1960s there have been thousands of scientific studies that were intended to discover if electromagnetic energy had an adverse affect on biological tissue. A large number of these studies, designed and performed by biologists, did not accurately expose the subjects to known levels of electromagnetic energy. A field of expertise in RF engineering, called dosimetry, was developed to accurately determine the exact field strengths of both electrical and magnetic fields to which subjects were exposed. It has been imperative that an expert in electromagnetic dosimetry be involved in study design, though even today this requirement is often ignored. The RF Safety committee contains expertise in dosimetry that often discovers experimental errors in published results due to misstatements of the amount of exposure that subjects experienced.

Epidemiological studies have the potential to recognize disease trends in populations. However, they can also develop misleading results. Epidemiology looks for health trends among people with similar types of exposures as compared to a similar group of people that does not have the same type of exposure. (This type of study has become difficult to perform with cellular telephones because it is hard to find people who do not use them). The great diversity of the population makes it difficult to know that there is not some other exposure that affects the study group. The RF Safety committee contains expertise in epidemiology to make sense of claims based on epidemiological evidence, and the review of the methods and results can reveal a lesser impact of the study than the author or the press had implied.

Some experimental studies correctly demonstrate biological changes due to exposure to electromagnetic fields. A change in a biological tissue that occurs because of the presence of some form of energy may be an interesting finding, but it does not imply that this change will lead to a public health problem. (An obvious example is contraction of the eye pupil in the presence of bright light, a form of electromagnetic energy). The RF Safety Committee contains expertise in Public Health that helps to determine if there may be a correlation between a laboratory finding and any potential concern for the health of people in our society.

The ARRL RF Safety Committee serves as a resource to the ARRL Board of Directors, providing advice that helps them formulate ARRL policy related to RF safety. The RFSC interacts with the ARRL HQ staff to ensure that RF safety is appropriately addressed in ARRL publications and on the ARRL website. The Amateur Radio community corresponds with the RFSC for help with RF safety-related questions and problems. RFSC members monitor and analyze relevant published research. Its members participate in standards coordinating committees and other expert committees related to RF safety. The RFSC is responsible for writing the RF safety text that is included in ARRL publications. The accuracy of RF safety-related issues in articles submitted to *QST* and *QEX* are confirmed by committee members. The RFSC also participates in developing the RF safety questions for FCC amateur question pools and works with the FCC in developing its environmental regulations. Radio amateurs with questions related to RF safety can contact the RFSC via its liaison, Ed Hare, W1RFI, **w1rfi@arrl.org**. The RFSC maintains a webpage at **www.arrl.org/arrl-rf-safety-committee**.

THERMAL EFFECTS OF RF ENERGY

Body tissues that are subjected to *very high* levels of RF energy may suffer serious heat damage. These effects depend on the frequency of the energy, the power density of the RF field that strikes the body and factors such as the polarization of the wave and the grounding of the body.

At frequencies near the body's natural resonances RF energy is absorbed more efficiently. In adults, the primary resonance frequency is usually about 35 MHz if the person is grounded, and about 70 MHz if insulated from the ground. Various body parts are resonant at different frequencies. Body size thus determines the frequency at which most RF energy is absorbed. As the frequency is moved farther from resonance, RF energy absorption becomes less efficient. *Specific absorption rate (SAR)* is a measure that takes variables such as resonance into account to describe the rate at which RF energy is absorbed in tissue, typically measured in watts per kilogram of tissue (W/kg).

Maximum permissible exposure (MPE) limits define the maximum electric and magnetic field strengths, and the plane-wave equivalent power densities associated with these fields, that a person may be exposed to without harmful effect, and are based on whole-body SAR safety levels. The safe exposure limits vary with frequency as the efficiency of absorption changes. The MPE limits Safety factors are included to insure that the MPE field strength will never result in an unsafe SAR.

Thermal effects of RF energy are usually not a major concern for most radio amateurs because the power levels normally used tend to be low and the intermittent nature of most amateur transmissions decreases total exposure. Amateurs spend more time listening than transmitting and many amateur transmissions such as CW and SSB use low-duty-cycle modes. With FM or RTTY, though, the RF is present continuously at its maximum level during each transmission. It is rare for radio amateurs to be subjected to RF fields strong enough to produce thermal effects, unless they are close to an energized antenna or unshielded power amplifier. Specific suggestions for avoiding excessive exposure are offered later in this chapter.

ATHERMAL EFFECTS OF EMF

Biological effects resulting from exposure to power levels of RF energy that do not generate measurable heat are called *athermal effects*. A number of athermal effects of EMF exposure on biological tissue have been seen in the laboratory. However, to date all athermal effects that have been discovered have had the same features: They are transitory, or go away when the EMF exposure is removed, and they have not been associated with any negative health effects.

28.3.2 Researching Biological Effects of EMF Exposure

The statistical basis of scientific research that confuses many non-scientists is the inability of science to state unequivocally that EMF is safe. Effects are studied by scientists using statistical inference where the "null hypothesis" assumes there is no effect and then tries to disprove this assumption by proving an "alternative hypothesis" that there is an effect. The alternative hypothesis can never be entirely disproved because a scientist cannot examine every possible case, so scientists only end up with a *probability* that the alternative hypothesis is *not* true. Thus, to be entirely truthful, a scientist can never say that something was proven; with respect to low-level EMF exposure, no scientist can guarantee that it is absolutely safe. At best, science can only state that there is a very low probability that it is unsafe. While scientists accept this truism, many members of the general public who are suspicious of EMF and its effects on humans see this as a reason to continue to be afraid.

There are two types of scientific study that are used to learn about the effects of EMF exposure on mammalian biology: laboratory and epidemiological.

LABORATORY STUDY

Scientists conduct laboratory research using animals to learn about biological mechanisms by which EMF may affect mammals. The main advantage of laboratory studies on the biological effects of EMF is that the exposures can be controlled very accurately.

Some major disadvantages of laboratory study also exist. EMF exposure may not affect the species of animals used in the investigations the same way that humans may respond. A common example of this misdirection occurred with eye research. Rabbits had been used for many years to determine that exposure of the eyes to high levels of EMF could cause cataracts. The extrapolation of these results to humans led to the fear that use of radio would harm one's vision. However, the rabbit's eye is on the surface of its skull while the human eye is buried deep within the bony orbit in the skull. Thus, the human eye receives much less exposure from EMF and is less likely to be damaged by the same exposures that had been used in the laboratory experiments on rabbits.

Some biological processes that affect tissue can take many years to occur and laboratory experiments on animals tend to be of shorter duration, in part because the life spans of most animals are much shorter than that of humans. For instance, a typical laboratory rat can be studied at most for two years, during which it progresses from youth to old age with all of the attendant physiological changes that come from normal aging. A disease process that takes multiple exposures over many years to occur is unlikely to be seen in a laboratory study with small animals.

EPIDEMIOLOGICAL RESEARCH

Epidemiologists look at the health patterns of large groups of people using statistical methods. In contrast to laboratory research, epidemiological research has very poor control of its subjects' exposures to EMF but it has the advantages of being able to analyze the effects of a lifetime of exposure and of being able to average out variations among large populations of subjects. By their basic design, epidemiological studies do not demonstrate cause and effect, nor do they postulate mechanisms of disease. Instead, epidemiologists look for associations between an environmental factor and an observed pattern of illness. Apparent associations are often seen in small preliminary studies that later are shown to have been incorrect. At best, such results are used to motivate more detailed epidemiological studies and laboratory studies that narrow down the search for cause-and-effect.

Some preliminary studies have suggested a weak association between exposure to EMF at home or at work and various malignant conditions including leukemia and brain cancer. A larger number of equally well-designed and performed studies, however, have found no association. Risk ratios as high as 2 have been observed in some studies. This means that the number of observed cases of disease in the test group is up to 2 times the "expected" number in the population. Epidemiologists generally regard a risk ratio of 4 or greater to be indicative of a strong association between the cause and effect under study. For example, men who smoke one pack of cigarettes per day increase their risk for lung cancer tenfold compared to nonsmokers and two packs per day increases the risk to more than 25 times the nonsmokers' risk.

Epidemiological research by itself is rarely conclusive, however. Epidemiology only identifies health patterns in groups — it does not ordinarily determine their cause. There are often confounding factors. Most of us are exposed to many different environmental hazards that may affect our health in various ways. Moreover, not all studies of persons likely to be exposed to high levels of EMF have yielded the same results (see sidebar on preliminary epidemiological studies).

28.3.3 Safe Exposure Levels

How much EMF energy is safe? Scientists and regulators have devoted a great deal of ef-

Preliminary Epidemiology

Just about every week you can pick up the newspaper and see a screaming banner headline such as: "Scientists Discover Link Between Radio Waves and Disease." So why are you still operating your ham radio? You've experienced the inconsistency in epidemiological study of diseases. This is something that every radio amateur should understand in order to know how to interpret the real meaning of the science behind the headlines and to help assuage the fears that these stories elicit in others.

Just knowing that someone who uses a radio gets a disease, such as cancer, doesn't tell us anything about the cause-and-effect of that disease. People came down with cancer, and most other diseases, long before radio existed. What epidemiologists try to identify is a group of people who all have a common exposure to something and all suffer from a particular disease in higher proportion than would be expected if they were not exposed. This technique has been highly effective in helping health officials notice excesses of disease due to things such as poisoning of water supplies by local industry and even massive exposures such as smoking. However, epidemiology rarely proves that an exposure causes a disease; rather it provides the evidence that leads to further study.

While the strength of epidemiology is that it helps scientists notice anomalies in entire populations, its weakness is that it is non-specific. An initial epidemiological study examines only two things: suspected exposures and rates of diseases. These studies are relatively simple and inexpensive to perform and may point to an apparent association that then bears further study. For instance, in one study of the causes of death of a selection of Amateur Radio operators, an excess of leukemia was suggested. The percentage of ham radio operators who died of leukemia in that study was higher than expected based on the percentage of the rest of the population that died of leukemia. By itself, this has little meaning and should not be a cause for concern, since the study did not consider anything else about the sample population except that they had ham licenses. Many other questions arise: Were the study subjects exposed to any unusual chemicals? Did any of the study subjects have a family history of leukemia? Did the licensed amateurs even operate radios, what kind and how often? To an epidemiologist, this result might provide enough impetus to raise the funds to gather more specific information about each subject and perform a more complete study that strengthens the apparent associations. However, a slight excess of disease in a preliminary study rarely leads to further study. Commonly, an epidemiologist does not consider a preliminary study to be worth pursuing unless the ratio of excess disease, also called the risk ratio, is 4:1 or greater. Unfortunately, most news reporters are not epidemiologists and do not understand this distinction. Rather, a slight excess of disease in a preliminary study can lead to banner headlines that raise fear in the society, causing unreasonable resistance to things like cell phones and ham radios.

Headlines that blow the results of preliminary epidemiological studies out of proportion are rarely followed by retractions that are as visible if the study is followed up by one that is more complete and shows no association with disease. In the case of the aforementioned epidemiological study of hams' licensing and death records, overblown publicity about the results has led to the urban legend that ham radio operators are likely to come down with leukemia. Not only is this an unfounded conclusion due to the preliminary nature of the original study, but a similar study was recently performed by the National Cancer Institute using a far larger number of subjects and no significant excess of any disease was found. Hams should be able to recognize when sensationalistic headlines are based on inconclusive science and should be prepared to explain to their families, friends and neighbors just how inconclusive such results are.

fort to deciding upon safe RF-exposure limits. This is a very complex problem, involving difficult public health and economic considerations. The recommended safe levels have been revised downward several times over the years — and not all scientific bodies agree on this question even today. The latest Institute of Electrical and Electronics Engineers (IEEE) C95.1 standard for recommended radio frequency exposure limits was published in 2006, updating one that had previously been published in 1991 and adopted by the American National Standards Institute (ANSI) in 1992. In the new standard changes were made to better reflect the current research, especially related to the safety of cellular telephones. At some frequencies the new standard determined that higher levels of exposure than previously thought are safe (see sidebar, "Where Do RF Safety Standards Come From?").

The IEEE C95.1 standard recommends frequency-dependent and time-dependent maximum permissible exposure levels. Unlike earlier versions of the standard, the 1991 and 2006 standards set different RF exposure limits in *controlled environments* (where energy levels can be accurately determined and everyone on the premises is aware of the presence of EM fields) and in *uncontrolled environments* (where energy levels are not known or where people may not be aware of the presence of EM fields). FCC regulations adopted these concepts to include controlled/occupational and uncontrolled/general population exposure limits.

The graph in **Fig 28.22** depicts the 1991 IEEE standard (which is still used as the basis of FCC regulation). It is necessarily a complex graph, because the standards differ not only for controlled and uncontrolled environments but also for electric (E) fields and magnetic (H) fields. Basically, the lowest E-field exposure limits occur at frequencies between 30 and 300 MHz. The lowest H-field exposure levels occur at 100-300 MHz. The ANSI standard sets the maximum E-field limits between 30 and 300 MHz at a power density of 1 mW/cm^2 (61.4 V/m) in controlled environments — but at one-fifth that level (0.2 mW/cm^2 or 27.5 V/m) in uncontrolled environments. The H-field limit drops to 1 mW/cm^2 (0.163 A/m) at 100-300 MHz in controlled environments and 0.2 mW/cm^2 (0.0728 A/m) in uncontrolled environments. Higher power densities are permitted at frequencies below 30 MHz (below 100 MHz for H fields) and above 300 MHz, based on the concept that the body will not be resonant at those frequencies and will therefore absorb less energy.

In general, the ANSI/IEEE standard requires averaging the power level over time periods ranging from 6 to 30 minutes for power-density calculations, depending on the frequency and other variables. The ANSI/IEEE exposure limits for uncontrolled environments are lower than those for controlled environments, but to compensate for that the standard allows exposure levels in those environments to be averaged over much longer time periods (generally 30 minutes). This long averaging time means that an intermittent RF source (such as an Amateur Radio transmitter) will result in a much lower exposure than a continuous-duty station, with all other parameter being equal. Time averaging is based on the concept that the human body can withstand a greater rate of body heating (and thus, a higher level of RF energy) for a short time.

Another national body in the United States, the National Council for Radiation Protection and Measurement (NCRP), also has adopted recommended exposure guidelines. NCRP urges a limit of 0.2 mW/cm^2 for nonoccupational exposure in the 30- 300 MHz range. The NCRP guideline differs from IEEE in that it takes into account the effects of modulation on an RF carrier.

The FCC MPE regulations are based on a combination of the 1992 ANSI/IEEE standard and 1986 NCRP recommendations. The MPE limits under the regulations are slightly

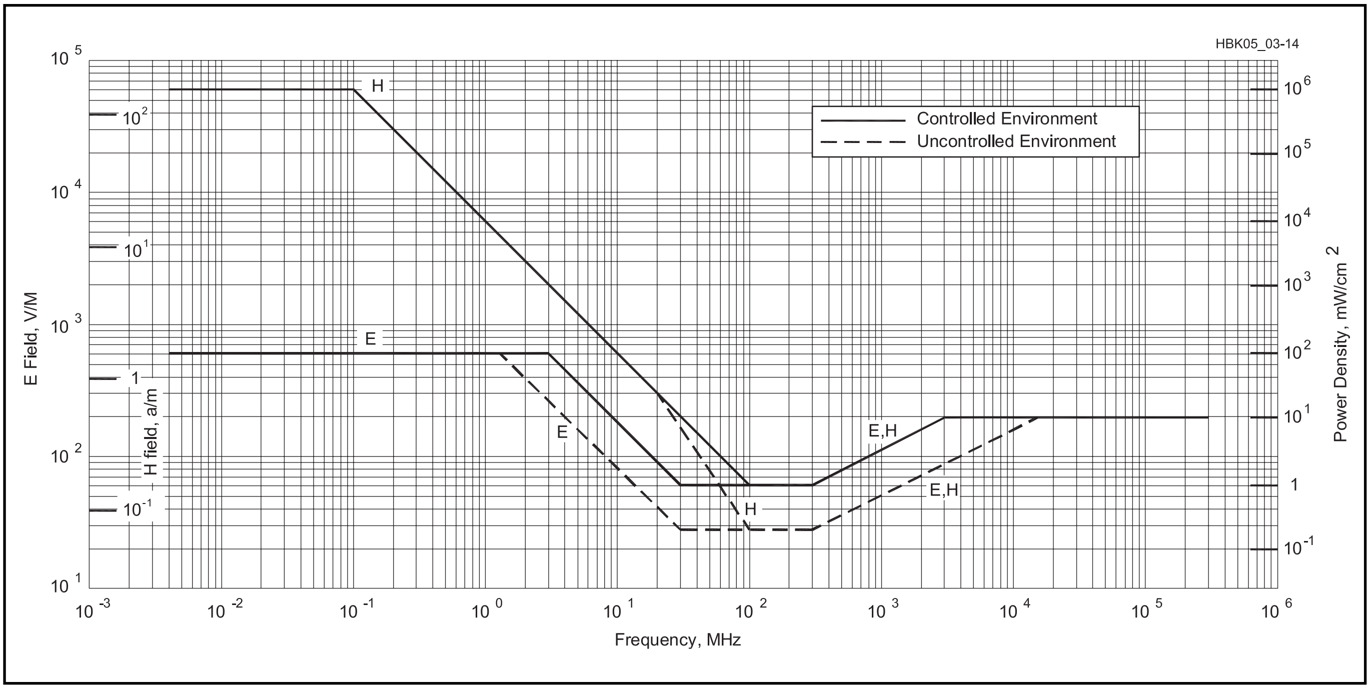

Fig 28.22 — 1991 RF protection guidelines for body exposure of humans. It is known officially as the "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz."

Where Do RF Safety Standards Come From?

So much of the way we deal with RF Safety is based on "Safety Standards." The FCC environmental exposure regulations that every ham must follow are largely restatements of the conclusions reached by some of the major safety standards. How are these standards developed and why should we trust them?

The preeminent RF safety standard in the world was developed by the Institute of Electrical and Electronics Engineers (IEEE). The most recent edition is entitled *C95.1 -2005: IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.* The IEEE C95.1 Standard has a long history. The first C95.1 RF safety standard was released in 1966, was less than 2 pages long and listed no references. It essentially said that for frequencies between 10 MHz and 100 GHz people should not be exposed to a power density greater than 10 mW/cm^2. The C95.1 standard was revised in 1974, 1982, 1991 and 2005. The latest (2005) edition of the standard was published in 2006, is 250 pages long and has 1143 references to the scientific literature. Most of the editions of the IEEE C95.1 standard were adopted by the American National Standards Institute (ANSI) a year or two after they were published by IEEE. The 2005 edition was adopted by ANSI in 2006.

The committee at IEEE that developed the latest revision to C95.1 is called International Committee on Electromagnetic Safety Technical Committee 95 Subcommittee 4 and had a large base of participants. The subcommittee was co-chaired by C-K Chou, Ph.D., of Motorola Laboratories, and John D'Andrea, PhD, of the U.S. Naval Health Research Center. The committee had 132 members, 42% of whom were from 23 countries outside the United States. The members of the committee represented academia (27%), government (34%), industry (17%), consultants (20%) and the general public (2%).

Early editions of C95.1 were based on the concept that heat generated in the body should be limited to prevent damage to tissue. Over time the standard evolved to protect against *all known adverse biological effects* regardless of the amount of heat generated. The 2005 revision was based on the principles that the standard should protect human health yet still be practical to implement, its conclusions should be based solely on scientific evidence and wherever scientifically defensible it should be harmonized with other international RF safety standards. It based its conclusions on 50 years of scientific study. From over 2500 studies on EMF performed during that time, 1300 were selected for their relevance to the health effects of RF exposure. The science in these studies was evaluated for its quality and methodology and 1143 studies were referenced in producing the latest standard.

Other major standards bodies have published similar standards. The National Council for Radiation Protection and Measurement (NCRP) published its safety standard entitled, *Report No. 86: Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields* in 1986. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) published its safety standard entitled *Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (Up to 300 GHz)* in 1998.

FCC RF Exposure Regulations

FCC regulations control the amount of RF exposure that can result from your station's operation (§§97.13, 97.503, 1.1307 (b)(c)(d), 1.1310, 2.1091 and 2.1093). The regulations set limits on the maximum permissible exposure (MPE) allowed from operation of transmitters in all radio services. They also require that certain types of stations be evaluated to determine if they are in compliance with the MPEs specified in the rules. The FCC has also required that questions on RF environmental safety practices be added to Technician and General license examinations.

THE RULES

Maximum Permissible Exposure (MPE)

All radio stations regulated by the FCC must comply with the requirements for MPEs, even QRP stations running only a few watts or less. The MPEs vary with frequency, as shown in **Table A**. MPE limits are specified in maximum electric and magnetic fields for frequencies below 30 MHz, in power density for frequencies above 300 MHz and all three ways for frequencies from 30 to 300 MHz. For compliance purposes, all of these limits must be considered *separately*. If any one is exceeded, the station is not in compliance. In effect, this means that both electric and magnetic field must be determined below 300 MHz but at higher frequencies determining either the electric or magnetic field is normally sufficient.

The regulations control human exposure to RF fields, not the strength of RF fields in any space. There is no limit to how strong a field can be as long as no one is being exposed to it, although FCC regulations require that amateurs use the minimum necessary power at all times (§97.311 [a]).

Table A

(From §1.1310) Limits for Maximum Permissible Exposure (MPE)

(A) Limits for Occupational/Controlled Exposure

Frequency Range (MHz)	*Electric Field Strength (V/m)*	*Magnetic Field Strength (A/m)*	*Power Density (mW/cm^2)*	*Averaging Time (minutes)*
0.3-3.0	614	1.63	(100)*	6
3.0-30	1842/f	4.89/f	(900/f^2)*	6
30-300	61.4	0.163	1.0	6
300-1500	—	—	f/300	6
1500-100,000	—	—	5	6

f = frequency in MHz
* = Plane-wave equivalent power density (see Notes 1 and 2).

(B) Limits for General Population/Uncontrolled Exposure

Frequency Range (MHz)	*Electric Field Strength (V/m)*	*Magnetic Field Strength (A/m)*	*Power Density (mW/cm^2)*	*Averaging Time (minutes)*
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	(180/f^2)*	30
30-300	27.5	0.073	0.2	30
300-1500	—	—	f/1500	30
1500-100,000	—	—	1.0	30

f = frequency in MHz
* = Plane-wave equivalent power density (see Notes 1 and 2).

Note 1: This means the equivalent far-field strength that would have the E or H-field component calculated or measured. It does not apply well in the near field of an antenna. The equivalent far-field power density can be found in the near or far field regions from the relationships: $P_d = |E_{total}|^2 / 3770$ mW/cm^2 or from $P_d = |H_{total}|^2 \times 37.7$ mW/cm^2.

Note 2: $|E_{total}|^2 = |E_x|^2 + |E_y|^2 + |E_z|^2$, and $|H_{total}|^2 = |H_x|^2 + |H_y|^2 + |H_z|^2$

Environments

The FCC has defined two tiers of exposure limits — *occupational/controlled limits* and *general population/uncontrolled limits*. Occupational/controlled limits apply when people are exposed as a condition of their employment and when they are aware of that exposure and can take steps to minimize it, if appropriate. General population/uncontrolled limits apply to exposure of the general public or people who are not normally aware of the exposure or cannot exercise control over it. The limits for general population/uncontrolled exposure are more stringent than the limits for occupational/controlled exposure. Specific definitions of the exposure categories can be found in Section 1.1310 of the FCC rules.

Although occupational/controlled limits are usually applicable in a workplace environment, the FCC has determined that they generally apply to amateur operators and members of their immediate households. In most cases, occupational/

different than the ANSI/IEEE limits and do not reflect all the assumptions and exclusions of the ANSI/IEEE standard.

28.3.4 Cardiac Pacemakers and RF Safety

It is a widely held belief that cardiac pacemakers may be adversely affected in their function by exposure to electromagnetic fields. Amateurs with pacemakers may ask whether their operating might endanger themselves or visitors to their shacks who have a pacemaker. Because of this, and similar concerns regarding other sources of EM fields, pacemaker manufacturers apply design methods that for the most part shield the pacemaker circuitry from even relatively high EM field strengths.

It is recommended that any amateur who has a pacemaker, or is being considered for one, discuss this matter with his or her physician. The physician will probably put the amateur into contact with the technical representative of the pacemaker manufacturer. These representatives are generally excellent resources, and may have data from laboratory or "in the field" studies with specific model pacemakers.

One study examined the function of a modern (dual chamber) pacemaker in and around an Amateur Radio station. The pacemaker generator has circuits that receive and process electrical signals produced by the heart, and also generate electrical signals that stimulate (pace) the heart. In one series of experiments, the pacemaker was connected to a heart simulator. The system was placed on top of the cabinet of a 1-kW HF linear amplifier during SSB and CW operation. In another test, the system was placed in close proximity to several 1 to 5-W 2-meter hand-held transceivers. The test pacemaker was connected to the heart simulator in a third test, and then placed on the ground 9 meters below and 5 meters in front of a three-element Yagi HF antenna. No interference with pacemaker function was observed in these experiments.

Although the possibility of interference cannot be entirely ruled out by these few observations, these tests represent more severe exposure to EM fields than would ordinarily be encountered by an amateur — with an average amount of common sense. Of course prudence dictates that amateurs with pace-

controlled limits can be applied to your home and property to which you can control physical access. The general population/uncontrolled limits are intended for areas that are accessible by the general public, such as your neighbors' properties.

The MPE levels are based on average exposure. An averaging time of 6 minutes is used for occupational/controlled exposure; an averaging period of 30 minutes is used for general population/uncontrolled exposure.

Station Evaluations

The FCC requires that certain amateur stations be evaluated for compliance with the MPEs. Although an amateur can have someone else do the evaluation, it is not difficult for hams to evaluate their own stations. The ARRL book *RF Exposure and You* contains extensive information about the regulations and a large chapter of tables that show compliance distances for specific antennas and power levels. Generally, hams will use these tables to evaluate their stations. Some of these tables have been included in the FCC's information — *OET Bulletin 65* and its *Supplement B* (available for downloading at the FCC's RF Safety website). If hams choose, however, they can do more extensive calculations, use a computer to model their antenna and exposure, or make actual measurements.

Categorical Exemptions

Some types of amateur stations do not need to be evaluated, but these stations must still comply with the MPE limits. The station licensee remains responsible for ensuring that the station meets these requirements.

The FCC has exempted these stations from the evaluation requirement because their output power, operating mode and frequency are such that they are presumed to be in compliance with the rules.

Stations using power equal to or less than the levels in **Table B** do not have to be evaluated on a routine basis. For the 100-W HF ham station, for example, an evaluation would be required only on 12 and 10 meters.

Hand-held radios and vehicle-mounted mobile radios that operate using a push-to-talk (PTT) button are also categorically exempt from performing the routine evaluation.

Repeater stations that use less than 500 W ERP or those with antennas not mounted on buildings; if the antenna is at least 10 meters off the ground, also do not need to be evaluated.

Correcting Problems

Most hams are already in compliance with the MPE requirements. Some amateurs, especially those using indoor antennas or high-power, high-duty-cycle modes such as a RTTY bulletin station and specialized stations for moon bounce operations and the like may need to make adjustments to their station or operation to be in compliance.

The FCC permits amateurs considerable flexibility in complying with these regulations. As an example, hams can adjust their operating frequency, mode or power to comply with the MPE limits. They can also adjust their operating habits or control the direction their antenna is pointing.

More Information

This discussion offers only an overview of this topic; additional information can be found in *RF Exposure and You* and on the ARRL website at **www.arrl.org/rf-exposure**. The ARRL website has links to the FCC website, with OET Bulletin 65 and Supplement B and links to software that hams can use to evaluate their stations.

Table B

Power Thresholds for Routine Evaluation of Amateur Radio Stations

Wavelength Band	*Evaluation Required if Power* (watts) Exceeds:*
MF	
160 m	500
HF	
80 m	500
75 m	500
40 m	500
30 m	425
20 m	225
17 m	125
15 m	100
12 m	75
10 m	50
VHF (all bands)	50
UHF	
70 cm	70
33 cm	150
23 cm	200
13 cm	250
SHF (all bands)	250
EHF (all bands)	250
Repeater stations (all bands)	Non-building-mounted antennas: height above ground level to lowest point of antenna < 10 m *and* power > 500 W ERP Building-mounted antennas: power > 500 W ERP

*Transmitter power = Peak-envelope power input to antenna. For repeater stations only, power exclusion based on ERP (effective radiated power).

makers, who use handheld VHF transceivers, keep the antenna as far as possible from the site of the implanted pacemaker generator. They also should use the lowest transmitter output required for adequate communication. For high power HF transmission, the antenna should be as far as possible from the operating position, and all equipment should be properly grounded.

28.3.5 Low-Frequency Fields

There has been considerable laboratory research about the biological effects of power line EMF. For example, some separate studies have indicated that even fairly low levels of EMF exposure might alter the human body's circadian rhythms, affect the manner in which T lymphocytes function in the immune system and alter the nature of the electrical and chemical signals communicated through the cell membrane and between cells, among other things. Although these studies are intriguing, they do not demonstrate any effect of these low-level fields on the overall organism.

Much of this research has focused on low-frequency magnetic fields, or on RF fields that are keyed, pulsed or modulated at a low audio frequency (often below 100 Hz). Several studies suggested that humans and animals could adapt to the presence of a steady RF carrier more readily than to an intermittent, keyed or modulated energy source.

The results of studies in this area, plus speculations concerning the effect of various types of modulation, were and have remained somewhat controversial. None of the research to date has demonstrated that low-level EMF causes adverse health effects.

Given the fact that there is a great deal of ongoing research to examine the health consequences of exposure to EMF, the American Physical Society (a national group of highly respected scientists) issued a statement in May 1995 based on its review of available data pertaining to the possible connections of cancer to 60-Hz EMF exposure. Their report is exhaustive and should be reviewed by anyone with a serious interest in the field. Among its general conclusions are the following:

1. The scientific literature and the reports of reviews by other panels show no consistent, significant link between cancer and power line fields.

2. No plausible biophysical mechanisms for the systematic initiation or promotion of cancer by these extremely weak 60-Hz fields have been identified.

3. While it is impossible to prove that no deleterious health effects occur from exposure to any environmental factor, it is necessary to demonstrate a consistent, significant, and causal relationship before one can conclude that such effects do occur.

In a report dated October 31, 1996, a committee of the National Research Council of the National Academy of Sciences has concluded that no clear, convincing evidence exists to show that residential exposures to electric and magnetic fields (EMF) are a threat to human health.

A National Cancer Institute epidemiological study of residential exposure to magnetic fields and acute lymphoblastic leukemia in children was published in the *New England Journal of Medicine* in July 1997. The exhaustive, seven-year study concludes that if there is any link at all, it is far too weak to be of concern.

In 1998, the US National Institute on Environmental Health Sciences organized a working group of experts to summarize the research on power-line EMF. The committee used the classification rules of the International Agency for Research on Cancer (IARC) and performed a meta-analysis to combine all past results as if they had been performed in a single study. The NIEHS working group concluded that the research did not show this type of exposure to be a carcinogen but could not rule out the possibility either. Therefore, they defined power-line EMF to be a Class 2b carcinogen under the IARC classification. The definition, as stated by the IARC is: "Group 2B: The agent is possibly carcinogenic to humans. There is limited pidemiological evidence plus limited or inadequate animal evidence." Other IARC Class 2b carcinogens include automobile exhaust, chloroform, coffee, ceramic and glass fibers, gasoline and pickled vegetables.

Readers may want to follow this topic as further studies are reported. Amateurs should be aware that exposure to RF and ELF (60 Hz) electromagnetic fields at all power levels and frequencies has not been fully studied under all circumstances. "Prudent avoidance" of any avoidable EMF is always a good idea. Prudent avoidance doesn't mean that amateurs should be fearful of using their equipment. Most amateur operations are well within the MPE limits. If any risk does exist, it will almost surely fall well down on the list of causes that may be harmful to your health (on the other end of the list from your automobile). It does mean, however, that hams should be aware of the potential for exposure from their stations, and take whatever reasonable steps they can take to minimize their own exposure and the exposure of those around them.

Although the FCC doesn't regulate 60-Hz fields, some recent concern about EMF has focused on 60 Hz. Amateur Radio equipment can be a significant source of 60 Hz fields, although there are many other sources of this kind of energy in the typical home. Magnetic fields can be measured relatively accurately with inexpensive 60-Hz meters that are made by several manufacturers.

Table 28.4 shows typical magnetic field intensities of Amateur Radio equipment and various household items.

Table 28.4
Typical 60-Hz Magnetic Fields Near Amateur Radio Equipment and AC-Powered Household Appliances
Values are in milligauss.

Item	*Field*	*Distance*
Electric blanket	30-90	Surface
Microwave oven	10-100	Surface
	1-10	12 in.
IBM personal computer	5-10	Atop monitor
	0-1	15 in. from screen
Electric drill	500-2000	At handle
Hair dryer	200-2000	At handle
HF transceiver	10-100	Atop cabinet
	1-5	15 in. from front
1-kW RF amplifier	80-1000	Atop cabinet
	1-25	15 in. from front

(Source: measurements made by members of the ARRL RF Safety Committee)

28.3.6 Determining RF Power Density

Unfortunately, determining the power density of the RF fields generated by an amateur station is not as simple as measuring low-frequency magnetic fields. Although sophisticated instruments can be used to measure RF power densities quite accurately, they are costly and require frequent recalibration. Most amateurs don't have access to such equipment, and the inexpensive field-strength meters that we do have are not suitable for measuring RF power density.

Table 28.5 shows a sampling of measurements made at Amateur Radio stations by the Federal Communications Commission and the Environmental Protection Agency in 1990. As this table indicates, a good antenna well removed from inhabited areas poses no hazard under any of the ANSI/IEEE guidelines. However, the FCC/EPA survey also indicates that amateurs must be careful about using indoor or attic-mounted antennas, mobile antennas, low directional arrays or any other antenna that is close to inhabited areas, especially when moderate to high power is used.

Table 28.5
Typical RF Field Strengths Near Amateur Radio Antennas
A sampling of values as measured by the Federal Communications Commission and Environmental Protection Agency, 1990

Antenna Type	*Freq (MHz)*	*Power (W)*	*E Field (V/m)*	*Location*
Dipole in attic	14.15	100	7-100	In home
Discone in attic	146.5	250	10-27	In home
Half sloper	21.5	1000	50	1 m from base
Dipole at 7-13 ft	7.14	120	8-150	1-2 m from earth
Vertical	3.8	800	180	0.5 m from base
5-element Yagi at 60 ft	21.2	1000	10-20	In shack
			14	12 m from base
3-element Yagi at 25 ft	28.5	425	8-12	12 m from base
Inverted V at 22-46 ft	7.23	1400	5-27	Below antenna
Vertical on roof	14.11	140	6-9	In house
			35-100	At antenna tuner
Whip on auto roof	146.5	100	22-75	2 m antenna
			15-30	In vehicle
			90	Rear seat
5-element Yagi at 20 ft	50.1	500	37-50	10 m antenna

Ideally, before using any antenna that is in close proximity to an inhabited area, you should measure the RF power density. If that

is not feasible, the next best option is make the installation as safe as possible by observing the safety suggestions listed in **Table 28.6**.

It also is possible, of course, to calculate the probable power density near an antenna using simple equations. Such calculations have many pitfalls. For one, most of the situations where the power density would be high enough to be of concern are in the near field. In the near field, ground interactions and other variables produce power densities that cannot be determined by simple arithmetic. In the far field, conditions become easier to predict with simple calculations. (See the February 2013 *QST* article "Q and the Energy Stored Around Antennas" by Kai Siwiak, KE4PT and the **Antennas** chapter of this book for more information about stored energy density near antennas.)

The boundary between the near field and the far field depends on the wavelength of the transmitted signal and the physical size and configuration of the antenna. The boundary between the near field and the far field of an antenna can be as much as several wavelengths from the antenna.

Computer antenna-modeling programs are another approach you can use. *MININEC* or other codes derived from *NEC* (Numerical Electromagnetics Code) are suitable for estimating RF magnetic and electric fields around amateur antenna systems.

These models have limitations. Ground interactions must be considered in estimating near-field power densities, and the "correct ground" must be modeled. Computer modeling is generally not sophisticated enough to predict "hot spots" in the near field — places where the field intensity may be far higher than would be expected, due to reflections from nearby objects. In addition, "nearby objects" often change or vary with weather or the season, therefore the model so laboriously crafted may not be representative of the actual situation, by the time it is running on the computer.

Intensely elevated but localized fields often can be detected by professional measuring instruments. These "hot spots" are often found near wiring in the shack, and metal objects such as antenna masts or equipment cabinets. But even with the best instrumentation, these measurements also may be misleading in the near field. One need not make precise measurements or model the exact antenna system, however, to develop some idea of the relative fields around an antenna. Computer modeling using close approximations of the geometry and power input of the antenna will generally suffice. Those who are familiar with *MININEC* can estimate their power densities by computer modeling, and those who have access to professional power-density meters can make useful measurements.

While our primary concern is ordinarily the intensity of the signal radiated by an antenna, we also should remember that there are other potential energy sources to be considered. You also can be exposed to excessive RF fields directly from a power amplifier if it is operated without proper shielding. Transmission lines also may radiate a significant amount of energy under some conditions. Poor microwave waveguide joints or improperly assembled connectors are another source of incidental exposure.

Table 28.6
RF Awareness Guidelines

These guidelines were developed by the ARRL RF Safety Committee, based on the FCC/EPA measurements of Table 28.4 and other data.

• Although antennas on towers (well away from people) pose no exposure problem, make certain that the RF radiation is confined to the antennas' radiating elements themselves. Provide a single, good station ground (earth), and eliminate radiation from transmission lines. Use good coaxial cable or other feed line properly. Avoid serious imbalance in your antenna system and feed line. For high-powered installations, avoid end-fed antennas that come directly into the transmitter area near the operator.

• No person should ever be near any transmitting antenna while it is in use. This is especially true for mobile or ground-mounted vertical antennas. Avoid transmitting with more than 25 W in a VHF mobile installation unless it is possible to first measure the RF fields inside the vehicle. At the 1-kW level, both HF and VHF directional antennas should be at least 35 ft above inhabited areas. Avoid using indoor and attic-mounted antennas if at all possible. If open-wire feeders are used, ensure that it is not possible for people (or animals) to come into accidental contact with the feed line.

• Don't operate high-power amplifiers with the covers removed, especially at VHF/UHF.

• In the UHF/SHF region, never look into the open end of an activated length of waveguide or microwave feed-horn antenna or point it toward anyone. (If you do, you may be exposing your eyes to more than the maximum permissible exposure level of RF radiation.) Never point a high-gain, narrow-bandwidth antenna (a paraboloid, for instance) toward people. Use caution in aiming an EME (moonbounce) array toward the horizon; EME arrays may deliver an effective radiated power of 250,000 W or more.

• With hand-held transceivers, keep the antenna away from your head and use the lowest power possible to maintain communications. Use a separate microphone and hold the rig as far away from you as possible. This will reduce your exposure to the RF energy.

• Don't work on antennas that have RF power applied.

• Don't stand or sit close to a power supply or linear amplifier when the ac power is turned on. Stay at least 24 inches away from power transformers, electrical fans and other sources of high-level 60-Hz magnetic fields.

28.3.7 Further RF Exposure Suggestions

Potential exposure situations should be taken seriously. Based on the FCC/EPA measurements and other data, the "RF awareness" guidelines of Table 28.6 were developed by the ARRL RF Safety Committee. A longer version of these guidelines, along with a complete list of references, appeared in a *QST* article by Ivan Shulman, MD, WC2S ("Is Amateur Radio Hazardous to Our Health?" *QST*, Oct 1989, pp 31-34).

In addition, the ARRL has published a book, *RF Exposure and You* that helps hams comply with the FCC's RF-exposure regulations. The ARRL also maintains an RF-exposure news page on its website. See **www.arrl.org/rf-exposure**. This site contains reprints of selected *QST* articles on RF exposure and links to the FCC and other useful sites.

SUMMARY

The ideas presented in this chapter are intended to reinforce the concept that ham radio, like many other activities in modern life, does have certain risks. But by understanding the hazards and how to deal effectively with them, the risk can be minimized. Common-sense measures can go a long way to help us prevent accidents. Traditionally, amateurs are inventors, and experimenting is a major part of our nature. But reckless chance-taking is never wise, especially when our health and well-being is involved. A healthy attitude toward doing things the right way will help us meet our goals and expectations.

Contents

Chapter 29

Assembling a Station

Although many hams never try to build a major project, such as a transmitter, receiver or amplifier, they do have to assemble the various components into a working station. There are many benefits to be derived from assembling a safe, comfortable, easy-to-operate collection of radio gear, whether the shack is at home, in the car or in a field. This chapter will detail some of the "how tos" of setting up a station for fixed, mobile and portable operation. Such topics as station location, finding adequate power sources, station layout and cable routing are covered. It includes contributions from Wally Blackburn, AA8DX, a section on mobile installations from Alan Applegate, KØBG. and information on gasoline generators from Kirk Kleinschmidt, NTØZ. Rick Hilding, K6VVA, contributed the section on remote stations.

Chapter 29 — CD-ROM Content

Portable Stations

- "A Look at Gasoline Powered Inverter Generators," by Bob Allison, WB1GCM
- "Field Day Towers — Doing it Right" by Ward Silver, NØAX and Don Daso, K4ZA

Remote Stations

- "Remote Station Resources by K6VVA - 2014 Edition" — a list of resources for remote station builders

29.1 Fixed Stations

Regardless of the type of installation you are attempting, good planning greatly increases your chances of success. Take the time to think the project all the way through, consider alternatives, and make rough measurements and sketches during your planning and along the way. You will save headaches and time by avoiding "shortcuts." What might seem to save time now may come back to haunt you with extra work when you could be enjoying your shack.

One of the first considerations should be to determine what type of operating you intend to do. While you do not want to strictly limit your options later, you need to consider what you want to do, how much you have to spend and what room you have to work with. There is a big difference between a casual operating position and a "big gun" contest station, for example.

29.1.1 Selecting a Location

Selecting the right location for your station is the first and perhaps the most important step in assembling a safe, comfortable, convenient station. The exact location will depend on the type of home you have and how much space can be devoted to your station. Fortunate amateurs will have a spare room to devote to housing the station; some may even have a separate building for their exclusive use. Most must make do with a spot in the cellar or attic, or a corner of the living room is pressed into service.

Examine the possibilities from several angles. A station should be comfortable; odds are good that you'll be spending a lot of time there over the years. Some unfinished basements are damp and drafty — not an ideal environment for several hours of leisurely hamming. Attics have their drawbacks, too; they can be stifling during warmer months. If possible, locate your station away from the heavy traffic areas of your home. Operation of your station should not interfere with family life. A night of chasing DX on 80 meters may be exciting to you, but the other members of your household may not share your enthusiasm.

Keep in mind that you must connect your station to the outside world. The location you choose should be convenient to a good power source and an adequate ground. If you use a computer, you may need access to the Internert. There should be a fairly direct route to the outside for running antenna feed lines, rotator control cables and the like.

Although most homes will not have an "ideal" space meeting all requirements, the right location for you will be obvious after you scout around. The amateurs whose stations are depicted in **Figs 29.1** through **29.3** all found the right spot for them. Weigh the trade-offs and decide which features you

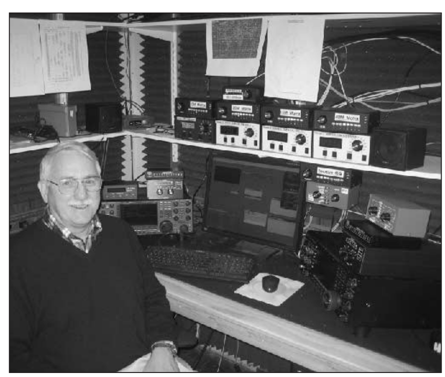

Fig 29.1 — Admiral Scott Redd (ret), KØDQ, operates this station at WW1WW in pursuit of top ranking in DX contests. Notice that the equipment on the operating desk is laid out logically and comfortably for long periods "in the chair." [Woody Beckford, WW1WW, photo]

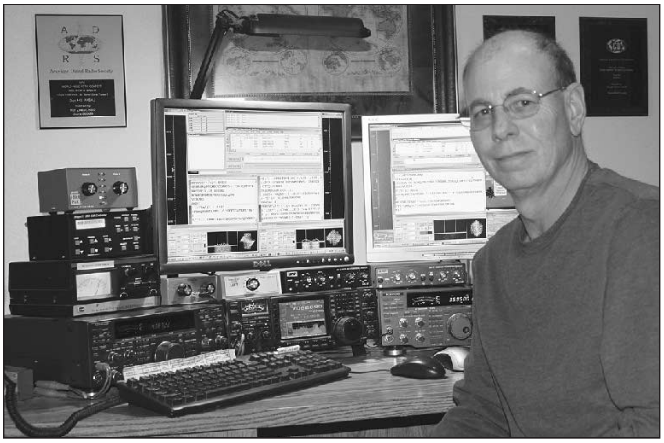

Fig 29.2 — Top RTTY contest operator Don Hill, AA5AU operates with low power from his effective station. RTTY operation emphasizes use of the computer mouse so Don's desk has lots of room for his "mouse hand". [Shay Hill, photo]

Fig 29.3 — Spreading out horizontally, John Sluymer, VE3EJ, has arranged his effective contest and DXing station to keep all of the controls at the same level for easy adjustment. [John Sluymer, VE3EJ, photo]

can do without and which are necessary for your style of operation. If possible pick an area large enough for future expansion.

29.1.2 Station Ground

Grounding is an important factor in overall station safety, as detailed in the **Safety** chapter. An effective ground system is necessary for every amateur station. The mission of the ground system is twofold. First, it reduces the possibility of electrical shock if something in a piece of equipment should fail and the chassis or cabinet becomes "hot." If connected to a properly grounded outlet, a three-wire electrical system grounds the chassis. Much amateur equipment still uses the ungrounded two-wire system, however. A ground system to prevent shock hazards is generally referred to as *dc ground*.

The second job the ground system must perform is to provide a low-impedance path to ground for any stray RF current inside the station. Stray RF can cause equipment to malfunction and contributes to RFI problems. This low-impedance path is usually called *RF ground*. In most stations, dc ground and RF ground are provided by the same system.

GROUND NOISE

Noise in ground systems can affect our sensitive radio equipment. It is usually related to one of three problems:

1) Insufficient ground conductor size
2) Loose ground connections
3) Ground loops

These matters are treated in precise scientific research equipment and certain industrial instruments by attention to certain rules. The ground conductor should be at least as large as the largest conductor in the primary power circuit. Ground conductors should provide a solid connection to both ground and to the equipment being grounded. Liberal use of lock washers and star washers is highly recommended. A loose ground connection is a tremendous source of noise, particularly in a sensitive receiving system.

Ground loops should be avoided at all costs. A short discussion here of what a ground loop is and how to avoid them may lead you down the proper path. A ground loop is formed when more than one ground current is flowing in a single conductor. This commonly occurs when grounds are "daisy-chained" (series linked). The correct way to ground equipment is to bring all ground conductors out radially from a common point to either a good driven earth ground or a cold-water system. If one or more earth grounds are used, they should be bonded back to the service entrance panel. Details appear in the **Safety** chapter.

Ground noise can affect transmitted and received signals. With the low audio levels required to drive amateur transmitters, and the ever-increasing sensitivity of receivers, correct grounding is critical.

29.1.3 Station Power

Amateur Radio stations generally require a 120-V ac power source. The 120-V ac is then converted to the proper ac or dc levels required for the station equipment. RF power amplifiers typically require 240 V ac for best operation.

Power supply theory is covered in the **Power Sources** chapter, and safety issues and station wiring are covered in the **Safety** chapter. If your station is located in a room with electrical outlets, you're in luck. If your station is located in the basement, an attic or another area without a convenient 120-V source, you will have to run a line to your operating position.

SURGE PROTECTION

Typically, the ac power lines provide an adequate, well-regulated source of electrical power for most uses. At the same time, these lines are fraught with power surges that, while harmless to most household equipment, may cause damage to more sensitive devices such as computers or test equipment. A common method of protecting these devices is through the use of surge protectors. More information on these devices and lightning protection is in the **Safety** chapter.

29.1.4 Station Layout

Station layout is largely a matter of personal taste and needs. It will depend mostly on the amount of space available, the equipment involved and the types of operating to be done. With these factors in mind, some basic design considerations apply to all stations.

THE OPERATING TABLE

The operating table may be an office or computer desk, a kitchen table or a custom-made bench. What you use will depend on space, materials at hand and cost. The two most important considerations are height and size of the top. Most commercial desks are about 29 inches above the floor. Computer tables are usually a couple inches lower for a more comfortable keyboard and mouse placement. This is a comfortable height for most adults. Heights much lower or higher than this may cause an awkward operating position.

The dimensions of the top are an important consideration. A deep (36 inches or more) top will allow plenty of room for equipment interconnections along the back, equipment about midway and room for writing or a keyboard and mouse toward the front. The length of the top will depend on the amount of equipment being used. An office or computer desk makes

Fig 29.4 — Mike Adams, N1EN makes the most of his desktop to operate on the HF and VHF+ bands. His laptop and tablet computers are an alternative to the larger desktop systems. He uses a full-size keyboard with the laptop. [Mike Adams, N1EN, photo]

a good operating table. These are often about 36 inches deep and 60 inches wide. Drawers can be used for storage of logbooks, headphones, writing materials, and so on. Desks specifically designed for computer use often have built-in shelves that can be used for equipment stacking. Desks of this type are available ready-to-assemble at most discount and home improvement stores. The low price and adaptable design of these desks make them an attractive option for an operating position. An example is shown in **Fig 29.4**.

ARRANGING THE EQUIPMENT

No matter how large your operating table, some vertical stacking of equipment may be necessary to allow you to reach everything from your chair. Stacking pieces of equipment directly on top of one another is not a good idea because most amateur equipment needs airflow around it for cooling. A shelf like that shown in **Fig 29.5** can improve equipment layout in many situations. Dimensions of the shelf can be adjusted to fit the size of your operating table.

When you have acquired the operating table and shelving for your station, the next task is arranging the equipment in a convenient, orderly manner. The first step is to provide power outlets and a good ground as described in a previous section. Be conservative in estimating the number of power outlets for your installation; radio equipment has a habit of multiplying with time, so plan for the future at the outset.

Fig 29.6 illustrates a sample station layout. The rear of the operating table is spaced about 1½ feet from the wall to allow easy access to the rear of the equipment. This installation incorporates two separate operating positions, one for HF and one for VHF. When the operator is seated at the HF operating position, the keyer and transceiver controls are within easy reach. The keyer, keyer paddle and transceiver are the most-often adjusted pieces of equipment in the station. The speaker is positioned right in front of the operator for the best possible reception. Accessory equipment not often adjusted, including the amplifier, antenna switch and rotator control box, is located on the shelf above the transceiver. The SWR/power meter and clock, often consulted but rarely touched, are located where the operator can view them without head movement. All HF-related equipment can be reached without moving the chair.

This layout assumes that the operator is right-handed. The keyer paddle is operated with the right hand, and the keyer speed and transceiver controls are operated with the left hand. This setup allows the operator to write or send with the right hand without having to cross hands to adjust the controls. If the operator is left-handed, some repositioning of equipment is necessary, but the idea is the same. For best results during CW operation, the paddle should be weighted to keep it from "walking" across the table. It should be oriented such that the operator's entire arm from wrist to elbow rests on the tabletop to prevent fatigue.

Some operators prefer to place the station transceiver on the shelf to leave the table top clear for writing or a computer keyboard and mouse. This arrangement leads to fatigue from having an unsupported arm in the air most of the time. If you rest your elbows on the tabletop, they will quickly become sore. If you rarely operate for prolonged periods, however, you may not be inconvenienced by having the transceiver on the shelf. The real secret to having a clear table top for logging, and so on, is to make the operating table deep enough that your entire arm from elbow to wrist rests on the table with the front panels of the equipment at your fingertips. This leaves plenty of room for paperwork, even with a microphone and keyer paddle on the table.

The VHF operating position in this station is similar to the HF position. The amplifier and power supply are located on the shelf. The station HF beam and VHF beam are on the same tower, so the rotator control box is located where it can be seen and reached from both operating positions. This operator is active on packet radio on a local VHF

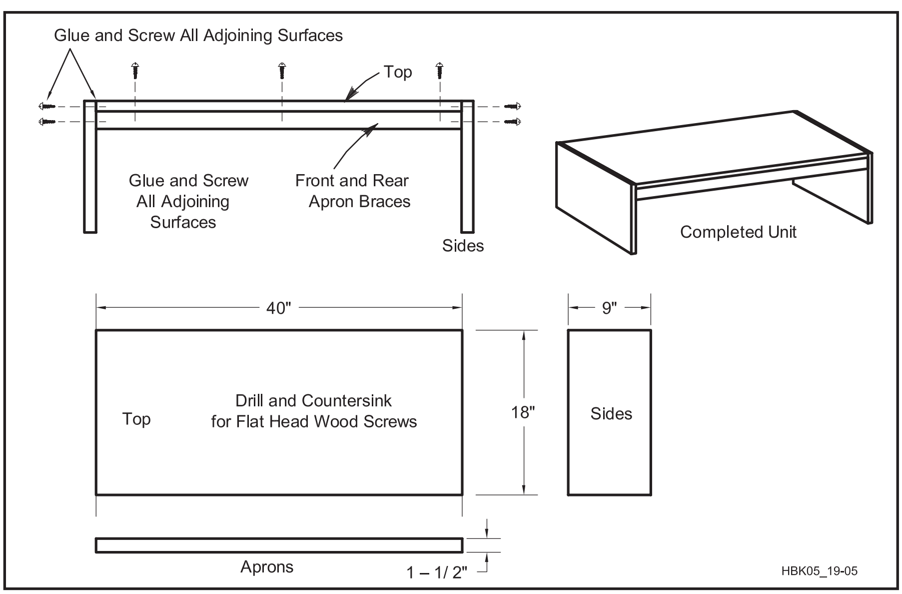

Fig 29.5 — A simple but strong equipment shelf can be built from readily available materials. Use ¾-inch plywood along with glue and screws for the joints for adequate strength.

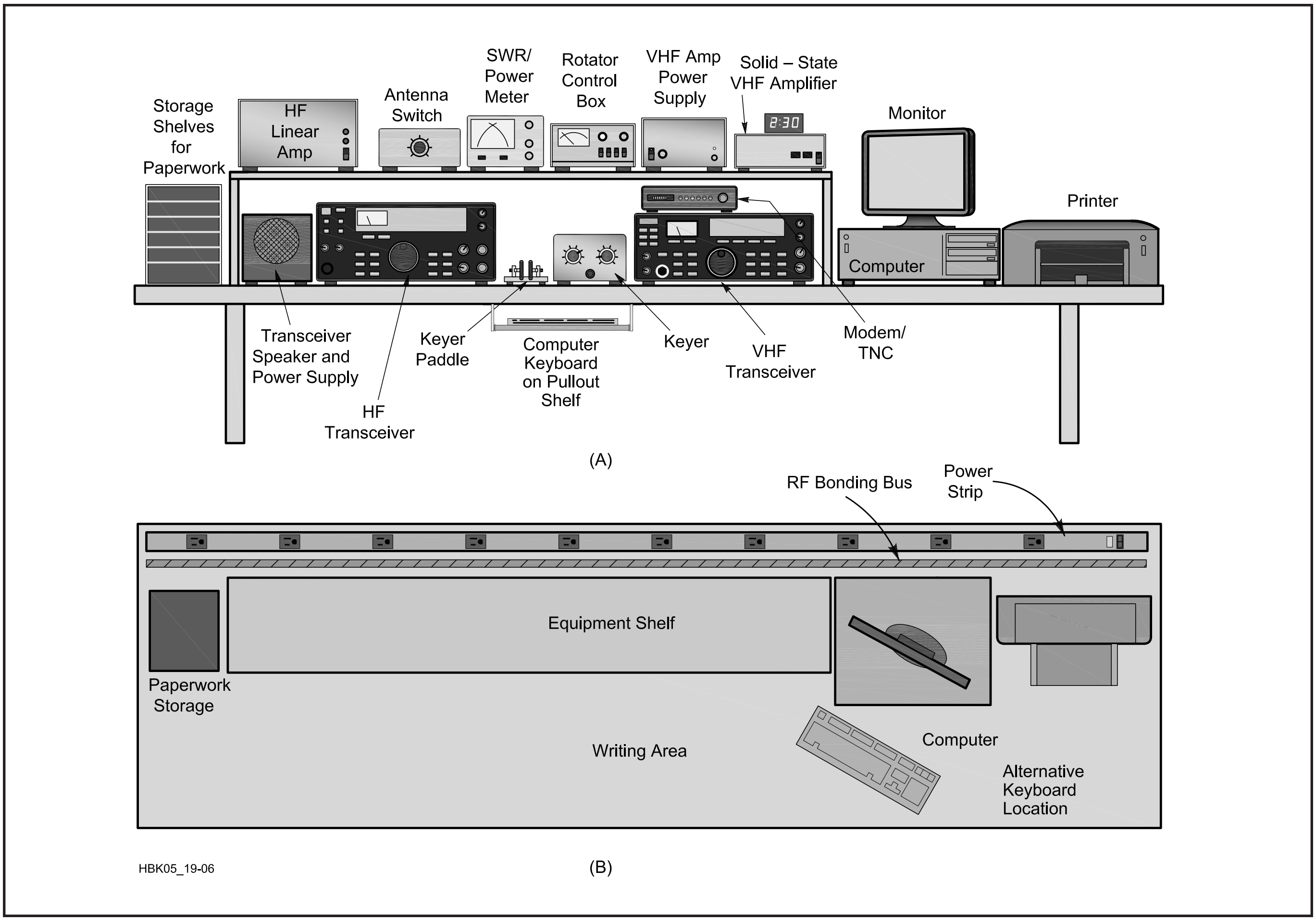

Fig 29.6 — Example station layout as seen from the front (A) and the top (B). The equipment is spaced far enough apart that air circulates on all sides of each cabinet. Equipment enclosures should be connected to the RF bonding bus with short pieces of #12 – #16 AWG wire (solid or stranded) or strap. See the Safety chapter for more information about ac safety and lightning grounding.

repeater, so the computer, printer and terminal node controller (TNC) are all clustered within easy reach of the VHF transceiver.

This sample layout is intended to give you ideas for designing your own station. Study the photos of station layouts presented here, in other chapters of this *Handbook* and in *QST*. Visit the shacks of amateur friends to view their ideas. Station layout is always changing as you acquire new gear, dispose of old gear, change operating habits and interests or become active on different bands. Configure the station to suit your interests, and keep thinking of ways to refine the layout. **Figs 29.7** and **29.8** show station arrangements tailored for specific purposes.

ERGONOMICS

Ergonomics is a term that loosely means "fitting the work to the person." If tools and equipment are designed around what people can accommodate, the results will be much more satisfactory. For example, in the 1930s research was done in telephone equipment manufacturing plants because use of long-nosed pliers for wiring switchboards required considerable force at the end of the hand's range of motion. A simple tool redesign resolved this issue.

Considerable attention has been focused on ergonomics in recent years because we have come to realize that long periods of time spent in unnatural positions can lead to repetitive-motion injuries. Much of this attention has been focused on people whose job tasks have required them to operate computers and other office equipment. While most Amateur Radio operators do not devote as much time to their hobby as they might in a full-time job, it does make sense to consider comfort and flexibility when choosing furniture and arranging it in the shack or workshop.

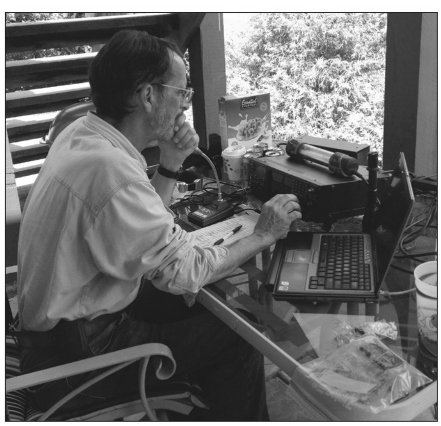

Fig 29.7 — Simple stations work best for portable operating, such as this 2013 Field Day setup for the two-operator NX9L team. [Photo courtesy of Andy Myers, NX9L]

Fig 29.8 — Richard, WB5DGR, uses a homebrew 1.5-kW amplifier to seek EME contacts from this nicely laid out station.

Adjustable height chairs are available with air cylinders to serve as a shock absorber. Footrests might come in handy if the chair is so high that your feet cannot support your lower leg weight. The height of tables and keyboards often is not adjustable.

Placement of computer screens should take into consideration the reflected light coming from windows. It is always wise to build into your sitting sessions time to walk around and stimulate blood circulation. Your muscles are less likely to stiffen, while the flexibility in your joints can be enhanced by moving around.

Selection of hand tools is another area where there are choices to make that may affect how comfortable you will be while working in your shack. Look for screwdrivers with pliable grips. Take into account how heavy things are before picking them up — your back will thank you.

FIRE EXTINGUISHERS

Fires in well-designed electronic equipment are not common but are known to occur. Proper use of a suitable fire extinguisher can make the difference between a small fire with limited damage and loss of an entire home. Make sure you know the limitations of your extinguisher and the importance of reporting the fire to your local fire department immediately.

Several types of extinguishers are suitable for electrical fires. The multipurpose dry chemical or "ABC" type units are relatively inexpensive and contain a solid powder that is nonconductive. Avoid buying the smallest size; a 5-pound capacity will meet most requirements in the home. ABC extinguishers are also the best choice for kitchen fires (the most common location of home fires). One disadvantage of this type is the residue left behind that might cause corrosion in electrical connectors. Another type of fire extinguisher suitable for energized electrical equipment is the carbon dioxide unit. CO_2 extinguishers require the user to be much closer to the fire, are heavy and difficult to handle, and are relatively expensive. For obvious reasons, water extinguishers are not suitable for fires in or near electronic equipment.

AIDS FOR HAMS WITH DISABILITIES

A station used by an amateur with physical disabilities or sensory impairments may require adapted equipment or particular layout considerations. The station may be highly customized to meet the operator's needs or just require a bit of "tweaking."

The myriad of individual needs makes describing all of the possible adaptive methods impractical. Each situation must be approached individually, with consideration to the operator's particular needs. However, many types of situations have already been encountered and worked through by others, eliminating the need to start from scratch in every case.

An excellent resource is the Courage Handi-Ham System. The Courage Handi-Ham System, a part of the Courage Center, provides a number of services to hams (and aspiring hams) with disabilities. These include study materials and a wealth of useful information on their comprehensive website. Visit **www.handiham.org** for more information.

29.1.5 Interconnecting Your Equipment

Once you have your equipment and get it arranged, you will have to interconnect it all. No matter how simple the station, you will at least have antenna, power and microphone or key connections. Equipment such as amplifiers, computers, TNCs and so on add complexity. By keeping your equipment interconnections well organized and of high quality, you will avoid problems later on.

Often, ready-made cables will be available. But in many cases you will have to make your own cables. A big advantage of making your own cables is that you can customize the length. This allows more flexibility in arranging your equipment and avoids unsightly extra cable all over the place. Many manufacturers supply connectors with their equipment along with pinout information in the manual. This allows you to make the necessary cables in the lengths you need for your particular installation.

Always use high quality wire, cables and connectors in your shack. Take your time and make good mechanical and electrical connections on your cable ends. Sloppy cables are often a source of trouble. Often the problems they cause are intermittent and difficult to track down. You can bet that they will crop up right in the middle of a contest or during a rare DX QSO! Even worse, a poor quality connection could cause RFI or even create a fire hazard. A cable with a poor mechanical connection could come loose and short a power supply to ground or apply a voltage where it should not be. Wire and cables should have good quality insulation that is rated high enough to prevent shock hazards.

Interconnections should be neatly bundled and labeled. Wire ties, masking tape or paper labels with string work well. See **Fig 29.9**. Whatever method you use, proper labeling makes disconnecting and reconnecting equipment much easier. **Fig 29.10** illustrates the number of potential interconnections in a modern, full-featured transceiver.

WIRE AND CABLE

The type of wire or cable to use depends on the job at hand. The wire must be of sufficient size to carry the necessary current. Use the tables in the **Component Data and References** chapter to find this information. Never use underrated wire; it will be a fire hazard. Be sure to check the insulation too. For high-voltage applications, the insulation must be rated at least a bit higher than the intended voltage. A good rule of thumb is

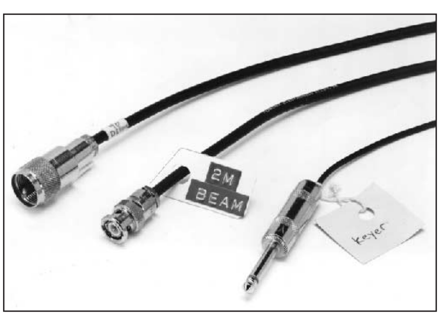

Fig 29.9 — Labels on the cables make it much easier to rearrange things in the station. Labeling ideas include masking tape, cardboard labels attached with string and labels attached to fasteners found on plastic bags (such as bread bags).

Fig 29.10 — The back of this Yaesu FT-950 transceiver shows some of the many types of connectors encountered in the amateur station. Note that this variety is found on a single piece of equipment.

to use a rating at least twice what is needed.

Use good quality coaxial cable of sufficient size for connecting transmitters, transceivers, antenna switches, antenna tuners and so on. RG-58 might be fine for a short patch between your transceiver and SWR bridge, but is too small to use between your legal-limit amplifier and antenna tuner. For more information, see the **Transmission Lines** chapter.

Hookup wire may be stranded or solid. Generally, stranded is a better choice since it is less prone to break under repeated flexing. Many applications require shielded wire to reduce the chances of RF getting into the equipment. RG-174 is a good choice for control, audio and some low-power RF applications. Shielded microphone or computer cable can be used where more conductors are necessary.

For RF connections, #12 – #16 AWG solid or stranded wire or solid strap are preferred. For indoor connections not exposed to the weather, flat-weave tinned braid strap is acceptable. Do not use braid salvaged from coaxial cable for RF connections.

CONNECTORS

Connectors are a convenient way to make an electrical connection by using mating electrical contacts. There are quite a few connector styles, but common terms apply to all of them. Pins are contacts that extend out of the connector body, and connectors in which pins make the electrical contact are called "male" connectors. Sockets are hollow, recessed contacts, and connectors with sockets are called "female." Connectors designed to attach to each other are called "mating connectors." Connectors with specially shaped bodies or inserts that require a complementary shape on a mating connector are called "keyed connectors." Keyed connectors ensure that the connectors can only go together one way, reducing the possibility of damage from incorrect mating.

Plugs are connectors installed on the end of cables and *jacks* are installed on equipment. *Adapters* make connections between two different styles of connector, such as between two different families of RF connectors. Other adapters join connectors of the same family, such as double-male, double-female and gender changers. *Splitters* divide a signal between two connectors.

While the number of different types of connectors is mind-boggling, many manufacturers of amateur equipment use a few standard types. If you are involved in any group activities such as public service or emergency-preparedness work, check to see what kinds of connectors others in the group use and standardize connectors wherever possible. Assume connectors are not waterproof, unless you specifically buy one clearly marked for outdoor use (and assemble it correctly).

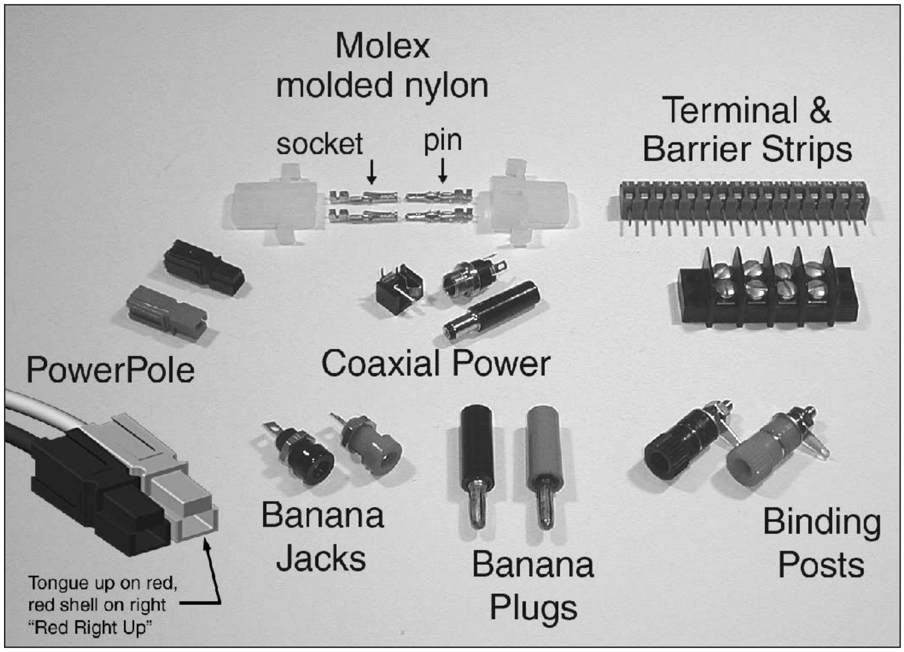

Fig 29.11 — These are the most common connectors used on amateur equipment to make power connections. The proper orientation for paired Powerpole connectors is with the red connector on the right and its tongue on top – "red-right-up". (Courtesy of Wiley Publishing, *Ham Radio for Dummies*, or *Two-Way Radios and Scanners for Dummies*)

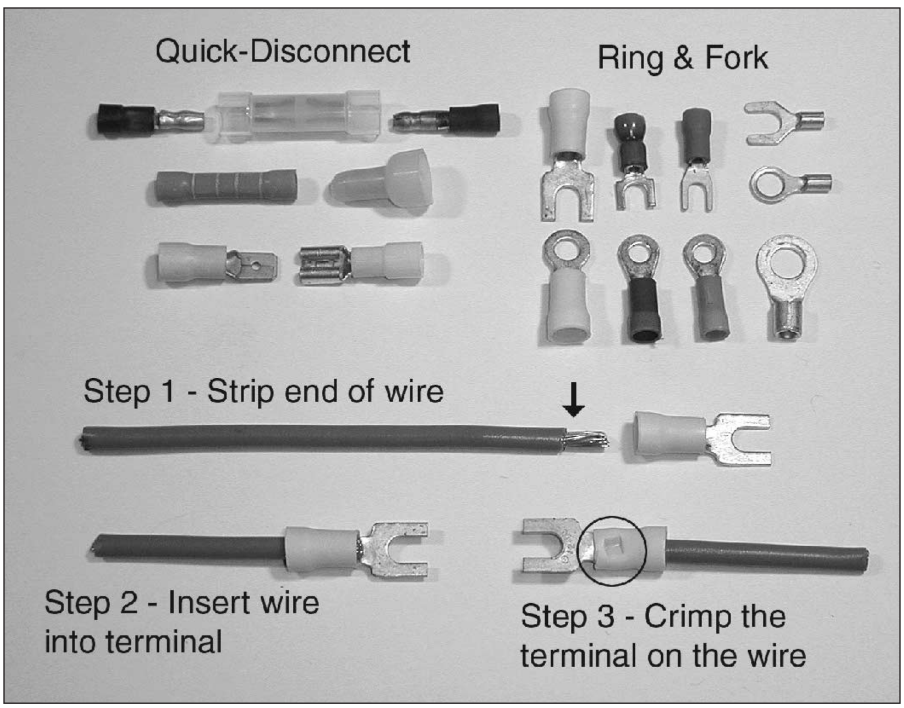

Fig 29.12 — Power connectors often use terminals that are crimped onto the end of wires with special crimping tools. (Courtesy of Wiley Publishing, *Ham Radio for Dummies*, or *Two-Way Radios and Scanners for Dummies*)

Power Connectors

Amateur Radio equipment uses a variety of power connectors. Some examples are shown in **Fig 29.11**. Most low power amateur equipment uses coaxial power connectors. These are the same type found on consumer electronic equipment that is supplied by a wall transformer power supply. Transceivers and other equipment that requires high current in excess of a few amperes often use Molex connectors (**www.molex.com** — enter "MLX" in the search window) with a white,

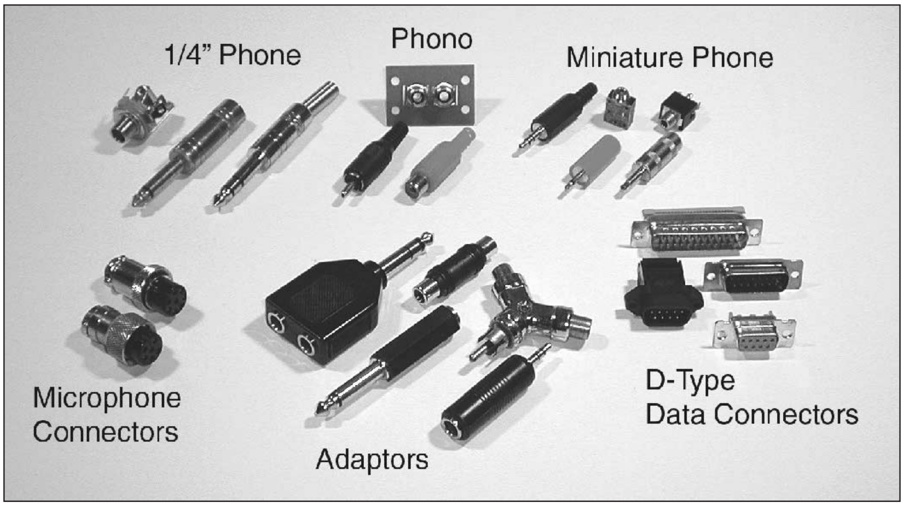

Fig 29.13 — Audio and data signals are carried by a variety of different connectors. Individual cable conductors are either crimped or soldered to the connector contacts. [Ward Silver, NØAX, photo]

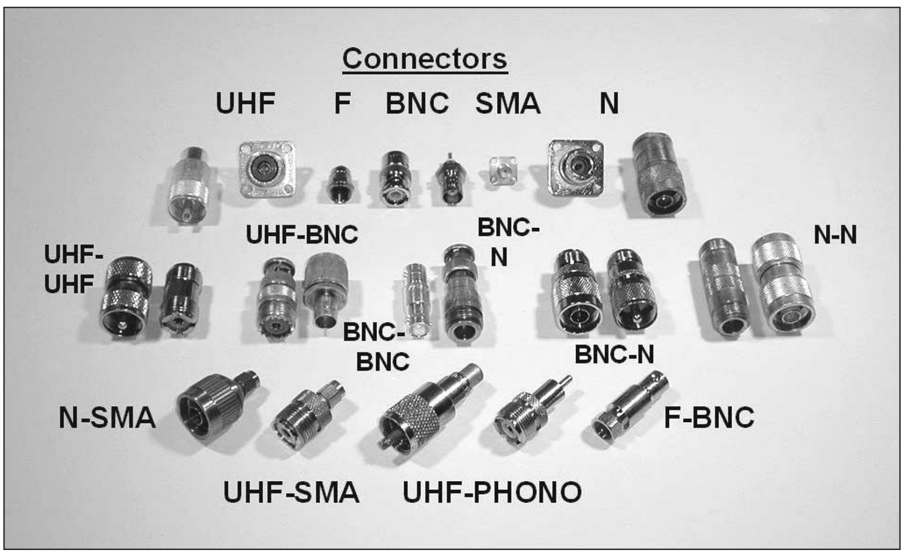

Fig 29.14 — Each type of RF connector is specially made to carry RF signals and preserve the shielding of coaxial cable. Adapters are available to connect one style of connector to another. [Ward Silver, NØAX, photo]

nylon body housing pins and sockets crimped on to the end of wires.

An emerging standard, particularly among ARES and other emergency communications groups, is the use of Anderson Powerpole connectors (**www.andersonpower.com**). These connectors are "sexless" meaning that any two connectors of the same series can be mated — there are no male or female connectors. By standardizing on a single connector style, equipment can be shared and replaced easily in the field. The standard orientation for pairs of these connectors is shown in Fig 29.11. Using this orientation increases the compatibility of your wiring with that of other hams.

Molex and Powerpole connectors use crimp terminals (both male and female) installed on the end of wires. A special crimping tool is used to attach the wire to the terminal and the terminal is then inserted into the body of the connector. Making a solid connection requires the use of an appropriate tool — do not use pliers or some other tool to make a crimp connection.

Some equipment uses terminal strips for direct connection to wires or crimp terminals, often with screws. Other equipment uses spring-loaded terminals or binding posts to connect to bare wire ends. **Fig 29.12** shows some common crimp terminals that are installed on the ends of wires using special tools.

Audio and Control Connectors

Consumer audio equipment and Amateur Radio equipment share many of the same connectors for the same uses. Phone plugs and jacks are used for mono and stereo audio circuits. These connectors, shown in **Fig 29.13** come in ¼ inch, ⅛ inch (miniature) and subminiature varieties. The contact at the end of the plug is called the tip and the connector at the base of the plug is the sleeve. If there is a third contact between the tip and sleeve, it is the ring (these are "stereo" phone connectors).

Phono plugs and jacks (sometimes called RCA connectors since they were first used on RCA brand equipment) are used for audio, video and low-level RF signals. They are also widely used for control signals.

The most common microphone connector on mobile and base station equipment is an 8-pin round connector. On older transceivers you may see 4-pin round connectors used for microphones. RJ-45 modular connectors (see the section on telephone connectors below) are often used in mobile and smaller radios.

RF Connectors

Feed lines used for radio signals require special connectors for use at RF frequencies. The connectors must have approximately the same characteristic impedance as the feed line they are attached to or some of the RF signal will be reflected by the connector. Inexpensive audio and control connectors cannot meet that requirement, nor can they handle the high power levels often encountered in RF equipment. Occasionally, phono connectors are used for HF receiving and low-power transmitting equipment.

By far, the most common connector for RF in amateur equipment is the UHF family shown in **Fig 29.14**. (The UHF designator has nothing to do with frequency.) A PL-259 is the plug that goes on the end of feed lines, and the SO-239 is the jack mounted on equipment. A "barrel" (PL-258) is a double-female adapter that allows two feed lines to be connected together. UHF connectors are typically used up to 150 MHz and can handle legal-limit transmitter power at HF.

UHF connectors have several drawbacks including lack of weatherproofing, poor performance above the 2 meter band and limited power handling at higher frequencies. The Type-N series of RF connectors addresses all of those needs. Type-N connectors are somewhat more expensive than UHF connectors, but they require less soldering and perform better in outdoor use since they are moisture resistant. Type-N connectors can be used to 10 GHz.

For low-power uses, BNC connectors are often used. BNC connectors are the standard for laboratory equipment, as well, and they are often used for dc and audio connections. BNC connectors are common on handheld radios for antenna connections. The newest handheld transceivers often use small, screw-on SMA type connectors for their antennas, though.

The type of connector used for a specific

job depends on the size of the cable, the frequency of operation and the power levels involved. More information on RF connectors may be found in the **Component Data and References** chapter.

Data Connectors

Digital data is exchanged between computers and pieces of radio equipment more than ever before in the amateur station. The connector styles follow those found on computer equipment.

D-type connectors are used for RS-232 (COM ports) and parallel (LPT port) interfaces. A typical D-type connector has a model number of "DB" followed by the number of connections and a "P" or "S" depending on whether the connector uses pins or sockets. For example, the DB-9P is used for PC COM1 serial ports.

USB connectors are becoming more popular in amateur equipment as the computer industry has eliminated the bulkier and slower RS-232 interface. A number of manufacturers make USB-to-serial converters that allow devices with RS-232 interfaces to be used with computers that only have USB interfaces.

Null modem or *crossover* adapters or cables have the same type of connector on each end. The internal connections between signal pins are swapped between ends so that inputs and outputs are connected together. This allows interfaces to be connected together directly without any intermediary equipment, such as an Ethernet switch or an RS-232 modem.

Pinouts for various common computer connectors are shown in the **Component Data and References** chapter. Several practical data interface projects are shown in the **Station Accessories** chapter and the **Digital Communications** supplement on the *Handbook* CD.

Telephone and Computer Network Connectors

Modular connectors are used for telephone and computer network connections. Connector part numbers begin with "RJ." The connectors are crimped on to multiconductor cables with special tools. The RJ11 connector is used for single- and double-line telephone system connection with 4 or 6 contacts. The RJ10 is a 4-contact connector for telephone handset connections. Ethernet computer network connections are made using RJ45 connectors with 8 contacts.

29.1.6 Documenting Your Station

An often neglected but very important part of putting together your station is properly documenting your work. Ideally, you should diagram your entire station from the ac power lines to the antenna on paper and keep the

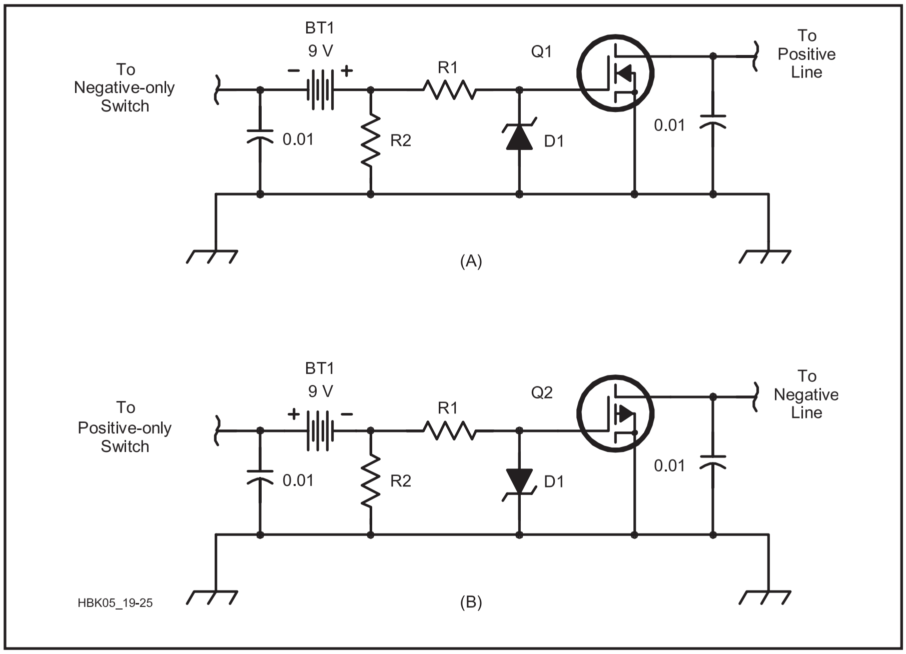

Fig 29.15 — Level-shifter circuits for opposite input and output polarities. At A, from a negative-only switch to a positive line; B, from a positive-only switch to a negative line.

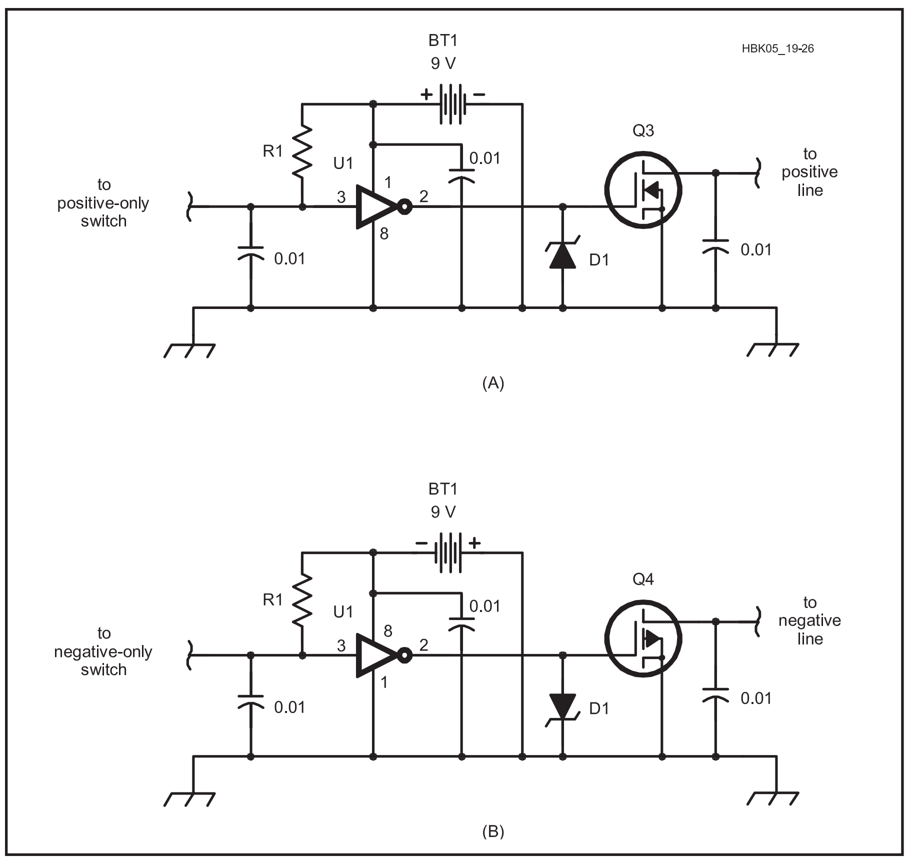

Fig 29.16 — Circuits for same-polarity level shifters. At A, for positive-only switches and lines; B, for negative-only switches and lines.

BT1 — 9-V transistor-radio battery.
D1 — 15-V, 1-W Zener diode (1N4744 or equiv).
Q3 — IRF620.
Q4 — IRF220 (see text).
R1 — 10 kΩ, 10%, ¼ W.
U1 — CD4049 CMOS inverting hex buffer, one section used (unused sections not shown; pins 5, 7, 9, 11 and 14 tied to ground).

information in a special notebook with sections for the various facets of your installation. Having the station well documented is an invaluable aid when tracking down a problem or planning a modification. Rather than having to search your memory for information on what you did a long time ago, you'll have the facts on hand.

Besides recording the interconnections and hardware around your station, you should also keep track of the performance of your equipment. Each time you install a new antenna, measure the SWR at different points in the band and make a table or plot a curve. Later, if you suspect a problem, you'll be able to look in your records and compare your SWR with the original performance.

In your shack, you can measure the power output from your transmitter(s) and amplifier(s) on each band. These measurements will be helpful if you later suspect you have a problem. If you have access to a signal generator, you can measure receiver performance for future reference.

29.1.7 Interfacing High-Voltage Equipment to Solid-State Accessories

Many amateurs use a variety of equipment manufactured or home brewed over a considerable time period. For example, a ham might be keying a '60s-era tube rig with a recently built microcontroller-based electronic keyer. Many hams have modern solid-state radios connected to high-power vacuum-tube amplifiers.

Often, there is more involved in connecting HV (high-voltage) vacuum-tube gear to solid-state accessories than a cable and the appropriate connectors. The solid-state switching devices used in some equipment will be destroyed if used to switch the HV load of vacuum tube gear. The polarity involved is important too. Even if the voltage is low enough, a key-line might bias a solid-state device in such a way as to cause it to fail. What is needed is another form of level converter.

MOSFET LEVEL CONVERTERS

While relays can often be rigged to interface the equipment, their noise, slow speed and external power requirement make them an unattractive solution in some cases. An alternative is to use power MOSFETs. Capable of handling substantial voltages and currents, power MOSFETs have become common design items. This has made them inexpensive and readily available.

Nearly all control signals use a common ground as one side of the control line. This leads to one of four basic level-conversion scenarios when equipment is interconnected:

1) A positive line must be actuated by a negative-only control switch.

2) A negative line must be actuated by a positive-only control switch.

3) A positive line must be actuated by a positive-only control switch.

4) A negative line must be actuated by a negative-only control switch.

In cases 3 and 4 the polarity is not the problem. These situations become important when the control-switching device is incapable of handling the required open-circuit voltage or closed-circuit current.

Case 1 can be handled by the circuit in **Fig 29.15A**. This circuit is ideal for interfacing keyers designed for grid-block keying to positive CW key lines. A circuit suitable for case 2 is shown in Fig 29.15B. This circuit is simply the mirror image of that in Fig 29.15A with respect to circuit polarity. Here, a P-channel device is used to actuate the negative line from a positive-only control switch.

Cases 3 and 4 require the addition of an inverter, as shown in **Fig 29.16**. The inverter provides the logic reversal needed to drive the gate of the MOSFET high, activating the control line, when the control switch shorts the input to ground.

Almost any power MOSFET can be used in the level converters, provided the voltage and current ratings are sufficient to handle the signal levels to be switched. A wide variety of suitable devices is available from most large mail-order supply houses.

29.2 Mobile Installations

Solid-state electronics and miniaturization have allowed mobile operators to equip their vehicles with stations rivaling base stations. Indeed, it is possible to operate from 160 meters through 70 cm with one compact transceiver. Adding versatility, most designed-for-mobile transceivers are set up so that the main body of the radio can be safely tucked under a seat, with the operating "head" conveniently placed for ease of use as shown in **Fig 29.17**.

Common power levels reach 100-150 W on HF, and 50-75 W on VHF. With proper antenna selection and placement (see the **Antennas** chapter), mobile stations can work the world, just like their base station counterparts. The only real difference between them is that you're trying to drive at the same time you are operating, and safe operating requires attention to the details.

For some of us living in antenna-restricted areas, mobile operating may offer the best solution for getting on the air. For others it is an enjoyable alternative to home-station operation. No matter which category you're in, you can enjoy success if you plan your installation with safety and convenience in mind.

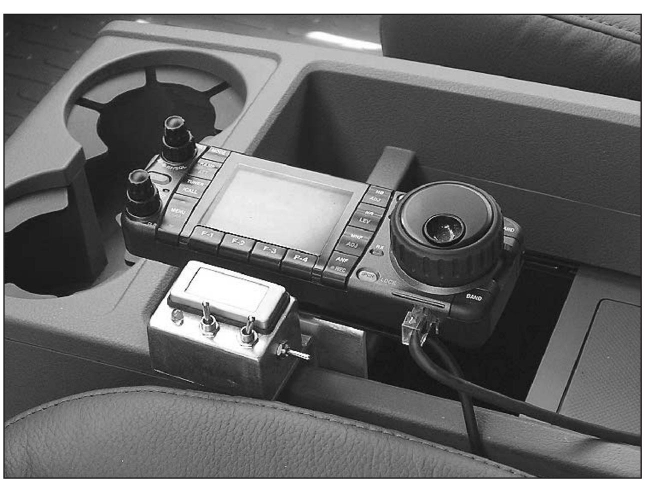

Fig 29.17 — In this mobile installation, the transceiver control head is mounted in the center console, next to a box with switches for adjusting the antenna.

29.2.1 Installation

Installing Amateur Radio equipment in modern vehicles can be quite challenging, yet rewarding, if basic safety rules are followed. All gear must be securely attached to the vehicle. Unsecured cup holder mounts, mounts wedged between cushions, elastic

Table 29.1
Mobile Mount Sources

Gamber Johnson	**www.gamberjohnson.com**
Havis-Shields	**www.havis.com**
Jotto Desk	**www.jottodesk.com**
PanaVise Products	**www.panavise.com**
RAM Mounting Systems	**www.ram-mount.com**

(A)

(B)

Fig 29.18 — At A, the transceiver control head is attached to one of many available mounts designed for this purpose. Mounts are typically highly adjustable, allowing the control head or radio to be positioned close to the operator. An antenna controller is mounted below the microphone. At B, HF and VHF transceiver control heads and the microphone are all mounted to the dashboard, within easy reach.

cords, hook-and-loop tape, magnets, or any other temporary mounting scheme *must be avoided*! Remember, if it isn't bolted down, it will become a missile in the event of a crash. The radio mounting location must avoid SRS (airbag) deployment zones — virtually eliminating the top of the dash in most modern vehicles — as well as vehicle controls (see the sidebar "Air Bags and Mobile Installations).

If you're not into building a specific mount for your vehicle, there are many no-holes-needed mounts available from Amateur Radio dealers. Some mounts are even designed for a specific transceiver make and model. **Table 29.1** lists some suppliers.

Two other points to keep in mind when choosing a mounting location are convenience and lack of distraction. Microphone and power cabling should be placed out of the way and properly secured. The transceiver's controls should be convenient to use and to view. See **Fig 29.18** for examples.

Mounting radios inside unvented center consoles and overhead bins should also be avoided. Modern mobile transceivers designed for remote mounting allow the main body to be located under a seat, in the trunk, or in another out-of-the-way place (**Fig 29.19**) but be sure there is plenty of ventilation.

If you drive off-road or on rough roads, you may also wish to consider using shock mounts, also known as "Lord Mounts" for their original manufacturer. For more information, see the product information on "Plateform Mounts" from the Astrotex Company at **www.astrotex.com/lord.htm**.

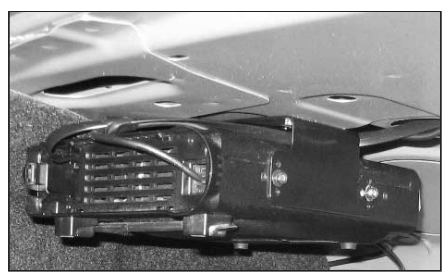

Fig 29.19 — The main body of the radio may be mounted in the vehicle's trunk or other out-of-the-way spot. Allow for plenty of ventilation.

Air Bags and Mobile Installation

Since 1998 all passenger vehicles are required to have Supplemental Restraint Systems (SRS), better known as *airbags*. Side airbags and airbags for rear seat passengers have become commonplace. When used in conjunction with seat belts, they've become a great life saving device, but they do have a drawback — they literally explode when they deploy!

Airbags deploy within 200 ms, expanding at about 200 mph, driven by gas from a controlled explosion. **Fig 29.A** drawing shows a typical vehicle with several air bags deployed in the passenger compartment. Any radio gear within range of an airbag will be ripped free with great force and flung about the interior. This should eliminate from consideration any dash-top mounting scheme including windshield suction cup (mobile phone) mounts, so often employed.

Fig 29.B shows the passenger compartment of a vehicle with airbags deployed after a minor collision that caused less than $300 damage to the bumper. Note the loose piece of dashboard on top of the deflated air bag and the broken windshield. These are typical effects of a deploying airbag, whether from the top or center of the dash. Knowing how airbags deploy, avoid mounting radio gear anywhere near them.

It is always a difficult task finding a suitable mounting location for a transceiver and/or control head that is out of airbag range yet easily seen and operated. One workaround is a gooseneck mount (see **Table 29.1** for a list of suppliers). These attach via a seat bolt (no hole needed). They're a good alternative as long as they're placed away from the passenger airbag deployment area (the whole right side of the dashboard). The dealer for your make and model may have additional guidelines for mounting radios and control heads in the car.

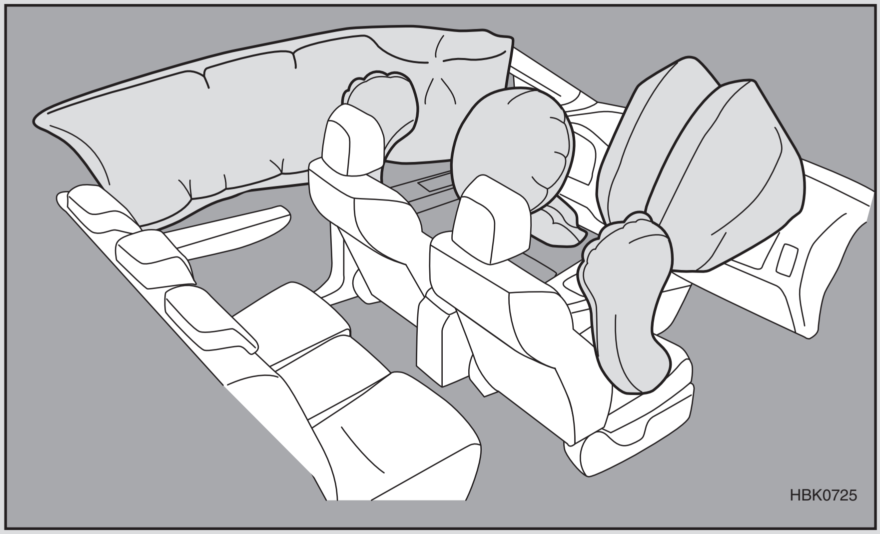

Fig 29.A — Airbag deployment zones in a modern vehicle.

Fig 29.B — Airbag deployment following a minor collision caused significant disruption inside the passenger compartment.

29.2.2 Coaxial Cable

Cable lengths in mobile installations seldom exceed 15 feet, so coax losses are not a major factor except for 70 cm and above. Good quality RG-58A or RG-8X size coax is more than adequate for HF and VHF. While there is nothing wrong with using RG-8 size coax (0.405 inch), it is stiffer and has a larger bending radius, making it harder to work with in most mobile applications.

There are some caveats when selecting coax. Avoid solid center conductors such as in standard RG-58. It has a propensity to kink, is susceptible to failure from vibration and can be difficult to solder properly. Both RG-58A and RG-8X use foam dielectric, and care is needed when soldering PL-259 connectors — especially when reducers are being used. The **Component Data and References** chapter illustrates the correct installation procedure.

29.2.3 Wiring

Proper wiring is an essential part of any mobile installation. Consider the following points when selecting materials and planning the cable routing.

• Wire needs to be correctly sized and fused stranded wire.

• All cables need to be protected from abrasion, heat, and chemicals.

• Wiring needs to be shortened and/or bundled with appropriate wire ties to avoid interaction with passengers and mechanical devices.. **Fig 29.20** shows a typical vehicle wiring tray.

Power cables should be connected directly

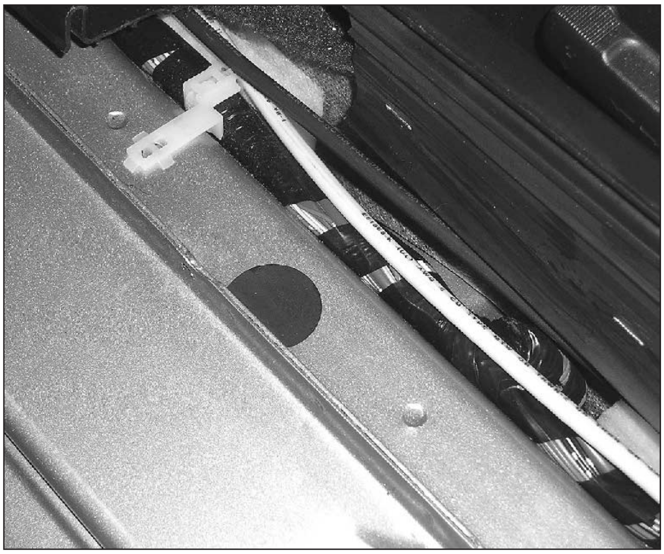

Fig 29.20 — Most vehicles have wiring troughs hidden behind interior body panels.

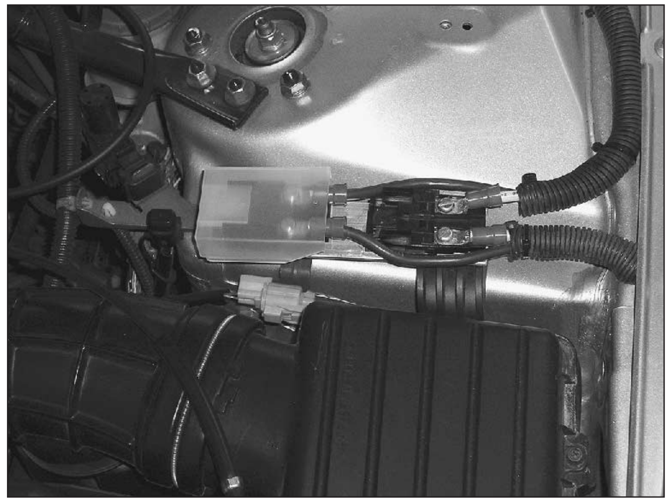

Fig 29.21 — Wiring attached to a fuse block.

to the battery following manufacturers' recommendations, with the requisite positive and negative lead fuses located close to the battery. **Fig 29.21** shows a typical fuse block. Accessory (cigarette lighter) sockets and power taps shouldn't be used except for very low current loads (<5 A), and then only with care. It pays to remember that a vehicle fire is both costly and dangerous! More information may be found at **www.fordemc.com/docs/download/Mobile_Radio_Guide.pdf** and **http://service.gm.com/techlineinfo/radio.html**.

The fuses supplied with most mobile transceivers are ATC style. Most automotive fuses are ATO. The ATC fuse element is completely sealed in plastic and the ATO is not. Since the power cable fuse holders are not waterproof, only an ATC fuse should be used if the fuse holder is exposed to the weather or located anywhere in the engine compartment. If an ATO is used, and water gets into the fuse, the fuse element corrodes and eventually fails.

Proper wiring also minimizes voltage drops and helps prevent ground loops. Modern solid-state transceivers will operate effectively down to 12.0 V dc (engine off). If the voltage drops below 11.6 V under load, some transceivers will reduce power, shut down or operate incorrectly. The vehicle chassis should not be used for ground returns; paint or other insulation can isolate different chassis sections and using a chassis return can create a ground loop.

Running cables through the engine firewall can be easy in some vehicles and nearly impossible in others. Using factory wiring grommets should be avoided unless they're not being used. In some cases, the only alternative is to drill your own hole. If you have any questions or concerns, have your local

Battery Connections

For many years, connecting mobile station power leads directly to the battery (or to the battery positive and ground tie-point) has been the standard recommendation. In vehicles equipped with EIS (Engine Idle Shutoff), however, additional sensing modules in the vehicle electrical system may require alternate connections.

With EIS, as soon as the vehicle stops for a short time, the engine shuts off and the battery voltage drops. To support the additional starting cycles, starters and batteries are more robust, but so are the sophistication of the electrical devices supporting them. The most important device is the ELD (Electronic Load Detector), typically located within the main fuse panel.

ELDs have been in use for many years to measure the current drawn by the accessories (air conditioning, lights, and so on), which allow the engine CPU to more accurately adjust the air/fuel mixture. However, on vehicles equipped with EIS, the ELD is located in battery's negative lead or its connector. (See your vehicle's service manual for the exact location of the ELD.) The ELD is used for *coulomb-counting* to estimate the battery's State of Charge (SoC). Measuring current during starting provides an estimate of the battery's Reserve Capacity (RC). This ensures the battery has enough reserves to restart the engine when the engine has to start again. (See the **Power Sources** chapter for more information on vehicle batteries.)

During engine shutdown, most EIS systems use a dc-to-dc converter to assure that the accessories have a constant voltage source for electric motors that power brakes, air conditioning, transmission servo pressure, fuel pumps, and engine cooling systems. A second trunk-mounted battery may be used, or even super-capacitors (low-voltage capacitors with many farads of capacitance). The converter and accessory operation is under the control of the Battery Monitoring System (BMS) and amateur transceiver wiring must avoid circumventing its operation.

Connecting the transceiver directly to the battery would bypass the BMS which is not recommended, nor is connecting the radio to the dc-to-dc converter, to the trunk-mounted accessory-power battery, or to existing vehicle wiring. In vehicles equipped with a BMS and/or ELD the correct method of connecting the radio is to connect the positive lead directly to the battery, and the negative lead to the battery's chassis grounding point. The negative lead fuse should not be removed! This avoids damage caused by a loose or broken battery connection, which could cause a Load Dump Transient (LDT) to occur. Should an LDT occur, the fuse might blow depending on the location of the battery lead failure. Without the fuse, damage to the transceiver could be the result.

If there is any doubt, check with your dealer about how the Battery Monitoring System (BMS) is connected and the recommended connection points for your radio's power leads. Be sure the connections you make are to points adequately rated for the load your radio presents. More information on batteries, alternators, and the newer vehicle power systems is available online at **www.k0bg.com**. — *Alan Applegate, KØBG*

mobile sound shop or two-way radio dealer install the wiring for you.

Power for ancillary equipment (wattmeters, remotely tuned antennas and so on) should follow the same wiring rules. The use of a multiple outlet power distribution panel such as a RigRunner (**www.westmountainradio.com**) is also recommended. They're convenient, and offer a second level of protection.

WIRE SIZE

The **Component Data and References** chapter lists the current-handling capabilities of various gauges of wire and cable. The correct wiring size is one that provides a low voltage drop (less than 0.5 V under full load). Don't use wire at its maximum current-current carrying capacity.

Here's the formula for calculating the cable assembly voltage drop (V_d):

$$V_d = [(R_W \times 2\,\ell \times 0.001) + 2\,k] \times I$$

where

R_W = resistance value (Ω per 1000 feet) from the **Component Data and References** chapter.

ℓ = overall length of the cable assembly including connectors, in feet.

k = nominal resistive value for one fuse and its holder. Note: Most power cables have two fuses. If yours doesn't, use 1 k in the formula. If you don't know the fuse and holder resistance, use a conservative value of 0.002 Ω.

I = peak current draw in amperes for a SSB transceiver, or steady state for an FM radio.

For example, the peak current draw for a 100 W transceiver is about 22 A, and a typical power cable length is 10 feet. Using the resistive values for 1000 feet of #10 AWG wire (0.9987 Ω), and a conservative value for the fuse resistances (0.002 Ω each), the calculated drop will be 0.527 V.

It's important to reiterate that the wire size should be selected for minimum voltage drop, not maximum power handling capability. The voltage drop is often referred to as "I-squared-R loss" — the current in amperes, squared, times the resistance — and should be held to a minimum whenever possible. In cabling, excessive I^2R losses can cause the wire to overheat with predictable results.

The insulation material of wire used in mobile installations should have a temperature rating of at least 90 °C, and preferably 105 °C. It should be protected with split-loom covering whenever possible, especially under-hood wiring.

Selecting the correct size fuse is also important. The average current draw for any given fuse should not exceed 60% of its rating. Thus, the correct fuse rating for a 22-A load is 30 A. That same 30-A fuse will handle a 40-A load for about 120 seconds, and a 100-A load for about 2 seconds. Therefore, it pays to be conservative when selecting the carrying capacities of both wire and fuses. **Fig 29.22** shows the characteristics of several sizes of automotive fuses.

29.2.4 Amplifiers

Mobile HF amplifiers have been around for many years, and with the advent of high-power solid state devices they are common. However, running high power in a mobile environment requires careful planning. Considerations include, but are not limited to:

- alternator current ratings and battery capacity
- wiring (in addition to safe current ratings, excessive voltage drop will create distortion of the output signal)
- antenna and feed line power ratings
- placement and secure mounting in the vehicle
- wiring and placing of remote controls

See **www.k0bg.com/amplifiers.html** for more information on these topics.

Before purchasing an amplifier, take a close look at your antenna installation and make sure it is operating efficiently. Using an amplifier with a poor antenna installation is counter-productive. Here's a rule of thumb applicable to any type of antenna: If the *unmatched* input SWR is less than 1.7:1 on 17 meters or any lower frequency band, then it isn't mounted correctly, and/or you need a better antenna. Whatever antenna you use, it must be capable of handling the amplifier power level — 500 W or more. More information on HF mobile antennas and installation techniques may be found in the **Antennas** chapter.

Mobile amplifiers for VHF/UHF operation are not as popular as they once were because

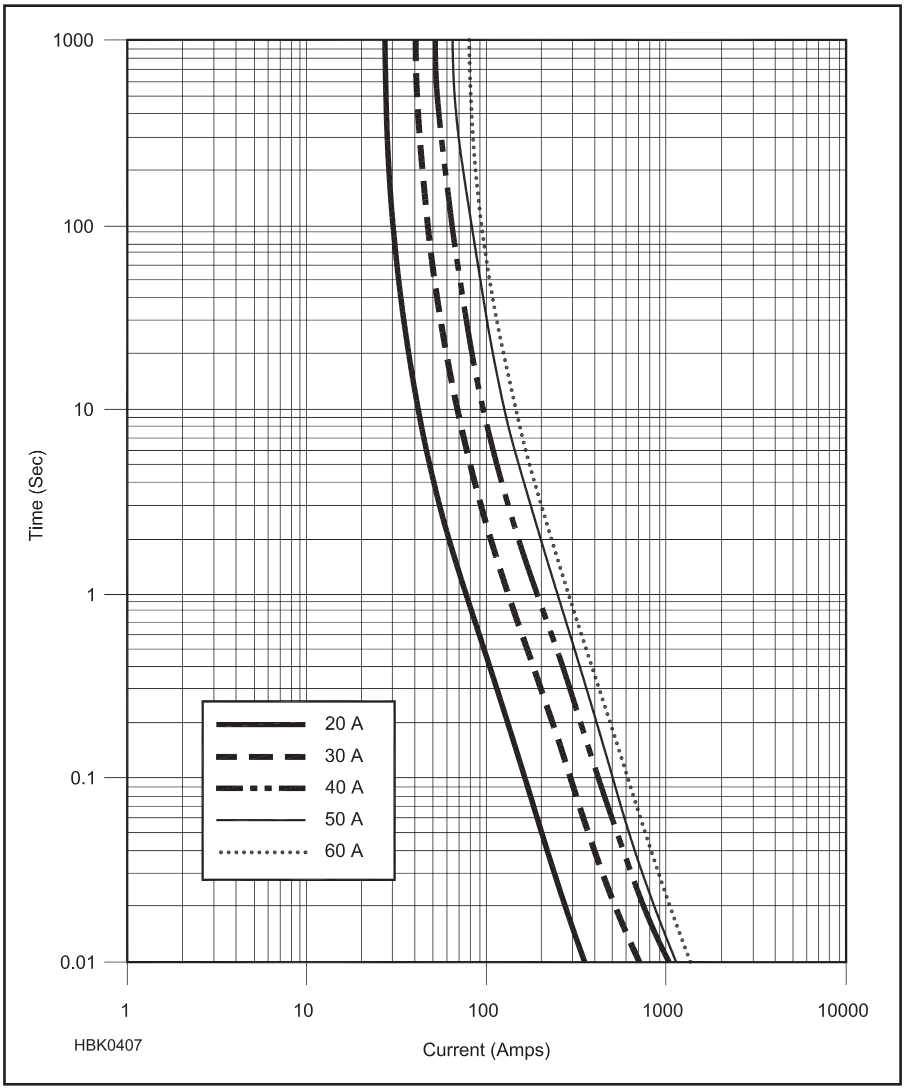

Fig 29.22 — Chart of opening delay versus current for five common sizes of Maxi fuses, the plastic-body high-current fuses common in vehicles. (*Based on a chart from Littelfuse Corp*)

most mobile transceivers have adequate output power (about 50 W). Boosting this to 150-300 W or more should be done with caution. Mobile VHF/UHF antennas for high power (>100 W) are rare, so check antenna ratings carefully. Those that are available need to be permanently mounted, and preferably on the roof to avoid inadvertent contact.

With any high-power mobile installation, pay careful attention to RF safety. More information on RF exposure can be found in the **Safety** chapter.

Fig 29.23 — Bonding vehicles parts — in this case, the trunk lid to the main body — can help reduce interference.

29.2.5 Interference Issues

In a mobile installation, radio frequency interference falls under two basic categories: *egress* (interference from the vehicle to your amateur station) and *ingress* (from your amateur gear to the vehicle). Most hams are familiar with ignition interference as it is the most common form of egress. RF interference to an auto sound system is a common form of ingress.

Both types of interference have unique solutions but they have at least one in common and that is *chassis bonding*. Chassis bonding refers to connecting accessory equipment or assemblies to the frame or chassis of the vehicle. For example, the exhaust system is isolated from the structure of the vehicle and acts like an antenna for the RFI generated by the ignition system. It should be bonded to the chassis in at least three places. **Fig 22.23** shows an example of bonding. More on these techniques is available at **www.k0bg.com/bonding.html**.

Other RFI egress problems are related to fuel pumps, HVAC and engine cooling fans, ABS sensors, data distribution systems and control system CPUs. These are best cured at the source by liberal use of snap-on ferrite cores on the wiring harnesses of the offending devices. Snap-on cores come is a variety of sizes and formulations called mixes. The best all-around ferrite core material for mobile RFI issues is Mix 31. Suitable cores are available from most Amateur Radio dealers. Unknown surplus units typically offer little HF attenuation and should be avoided. See the **RF Interference, RF Techniques,** and **Component Data and References** chapters for more information on ferrite cores.

Alternator whine can be another form of RFI egress. It is typically caused by an incorrectly mounted antenna resulting in a ground loop, rather than a defective alternator diode or inadequate dc power filtering as has been the traditional solution. Attempting to solve alternator whine with a dc filter can mask the problem and increases I^2R losses. Additional information on proper antenna mounting is in the **Antennas** chapter.

RFI ingress to the various on-board electronic devices is less common. The major causes are unchecked RF flowing on the control wires and common mode currents flowing on the coax cable of remotely-tuned HF antennas. Again, this points out the need to properly mount mobile antennas.

For more information on RFI issues, see the **RF Interference** chapter, *The ARRL RFI Handbook*, and the ARRL Technical Information Service (**www.arrl.org/tis**).

29.2.6 Operating

The most important consideration while operating mobile-in-motion is safety! Driver distraction is a familiar cause of vehicle crashes. While Amateur Radio use is far less distracting than mobile phones or texting, there are times when driving requires all of our attention. When bad weather, excessive traffic, or a construction zone require extra care, play it safe — hang up the microphone and turn off the radio!

In addition to properly installing gear, a few operating hints can make your journey less distracting. One of those is familiarization with your transceiver's menu functions and its microphone keys (if so equipped). Even then, complicated programming or adjustments are not something to do while underway.

Logging mobile contacts has always been difficult. Compact digital voice recorders have made that function easy and inexpensive. Units with up to 24 hours of recording time are available for less than $50.

For maximum intelligibility at the other end, avoid excessive speech processing and too much microphone gain. Don't shout into the microphone! It's human nature to increase your speaking level when excited or when the background level increases. In the closed cabin of a vehicle, your brain interprets the reflected sound from your own voice as an increase in background level. Add in a little traffic noise and by the end of your transmission you're in full shout mode! One solution is to use a headset and the transceiver's built-in monitor function. Doing so gives you direct feedback (not a time-delayed echo), and your brain won't get confused. Note that headset use is not legal in some jurisdictions and never legal if both ears are covered.

Overcoming vehicle ambient noise levels often requires the use of an external speaker and all too often it is an afterthought. Selecting a speaker that is too small accentuates high frequency noise which makes reception tiresome. Using adapters to interface with vehicle stereo systems isn't productive for the same reason. For speakers that are too large, mounting becomes a safety issue.

For best results, use at least a 4-inch speaker. Rather than mount it out in the open, mount it out of the way, under the driver's seat. This attenuates the high frequency noise, and enhances the mid-range response which increases intelligibility.

Most modern transceivers contain some form of DSP (digital signal processing) noise reduction as covered in the **DSP and Software Radio Design** chapter. Some are audio based and some are IF based, with the latter being preferred. But both types do a decent job of reducing high-frequency hiss, static spikes, and even ignition hash.

29.3 Portable Installations

Many amateurs experience the joys of portable operation once each year in the annual emergency exercise known as ARRL Field Day. Setting up an effective portable station requires organization, planning and some experience. For example, some knowledge of propagation is essential to picking the right band or bands for the intended communications link(s). Portable operation is difficult enough without dragging along excess equipment and antennas that will never be used.

Some problems encountered in portable operation that are not normally experienced in fixed-station operation include finding an appropriate power source and erecting an effective antenna. The equipment used should be as compact and lightweight as possible. A good portable setup is simple. Although you may bring gobs of gear to Field Day and set it up the day before, during a real emergency speed is of the essence. The less equipment to set up, the faster it will be operational.

29.3.1 Portable AC Power Sources

There are three popular sources of ac power for use in the field: batteries, dc-to-ac inverters, and gasoline powered generators. Batteries and inverters are covered in detail in the **Power Sources** chapter. This section will focus on gasoline powered generators. The book *Emergency Power for Radio Communications* by Mike Bryce, WB8VGE is another good resource for generator application information.

Essentially, a generator is a motor that's operating "backward." When you apply electricity to a motor, it turns the motor's shaft (allowing it to do useful work). If you need more rotational power, add more electricity or wind a bigger motor. Take the same motor and physically rotate its shaft and it generates electricity across the same terminals used to supply power when using the motor as a motor. Turn the shaft faster and the voltage and frequency increase. Turn it slower and they decrease. To some degree, all motors are generators and all generators are motors. The differences are in the details and in the optimization for specific functions.

A "motor" that is optimized for generating electricity is an alternator — just like the one in your car. The most basic generators use a small gas engine to power an ac alternator, the voltage and frequency of which depends on rotational speed. Because the generator is directly coupled to the engine, the generator's rotational speed is determined by the speed of the engine. If the engine is running too fast or too slow, the voltage and frequency of the output will be off. If everything is running at or near the correct speed, the voltage and frequency of the output will be a close approximation of the power supplied by the ac mains — a 120 V ac sine wave with a frequency of 60 Hz. These are referred to as *constant-speed generators*. Most consumer models use two pole armatures that run at 3600 RPM to produce a 60 Hz sine wave.

Inverter generators produce high-voltage, multiphase ac that is rectified to dc — similar to an automobile alternator. The dc power is then converted back to very clean and consistent ac power by a solid state power inverter controlled by a microprocessor. Unlike the constant-speed generators, inverters can run at idle while still providing power, increasing speed to meet additional

Fig 29.24 — Modern inverter generators from McCullough, Honda, Yamaha and Subaru/Robin. See Table 29.2 for a partial list of specifications.

Table 29.2
Specifications of the Inverter Generators Shown in Fig 29.24

Make and Model	*Output (W) (Surge/Cont)*	*Run Time (h) Full / 25% Load*	*Noise Range (dBA@21 feet)*	*Engine Type*	*Weight (Pounds)*	*Notes**
McCulloch FDD210M0	N/A / 1800	4 / N/A	60-70	105.6 cc, 3 HP	65 (shipping)	a,b
Honda EU2000i	2000 / 1600	4 /15	53-59	100 cc, OHC	46	a,b,c
Yamaha EF2400iS	2400 / 2000	N/A / 8.6	53-58	171 cc, OHV	70	a,b,c
Subaru/Robin R1700i	N/A / 1650	N/A / 8.5	53-59	2.4 HP, OHV	46	a,b,c

*a — has 12 V dc output; b — has "smart throttle" for better fuel economy; c — has low oil alert/shutdown

demand. This improves economy and reduces emissions. The most common models are available with capacities to approximately 2000 W output and some can be paralleled with special cables for higher capacity. The June 2012 *QST* Product Review "A Look at Gasoline Powered Inverter Generators" compares several popular models available at that time and is provided on the CD-ROM accompanying this book.

VOLTAGE REGULATION

There are several electronic and mechanical methods used to "regulate" the ac output — to keep the voltage and frequency values as stable as possible as generator and engine speeds vary because of current loads or other factors. Remember, a standard generator *must* turn at a specific speed to maintain output regulation, so when more power is drawn from the generator, the engine must supply more torque to overcome the increased physical/magnetic resistance in the generator's core — the generator *can't* simply spin faster to supply the extra oomph.

Most generators have engines that use mechanical or vacuum "governors" to keep the generator shaft turning at the correct speed. If the shaft slows down because of increasing generator demand, the governor "hits the gas" and draws energy stored in a heavy rotating flywheel, for example, to bring (or keep) the shaft speed up to par. The opposite happens if the generator is spinning too fast.

In addition to mechanical and vacuum speed regulating systems, generators that are a step up in sophistication additionally have electronic automatic voltage regulation (AVR) systems that use special windings in the generator core (and a microprocessor or circuit to monitor and control them) to help keep things steady near 120 V and 60 Hz. AVR systems can respond to short term load changes much more quickly than mechanical or vacuum governors alone. A decade ago AVR generators were the cream of the crop. Today, they're mostly used in medium to large units that can't practically employ inverters to maintain the best level of output regulation. You'll find them in higher quality 5 to 15 kW "home backup systems" and in many recreational vehicles.

Isolate Source and Load

Basic, inexpensive generators are intended to power lights, saws, drills, ac motors, electric frying pans and other devices that can reliably be run on "cruddy power." If you want the highest margin of safety when powering computers, transceivers and other sensitive electronics, a portable *inverter generator* is the best way to go. Some popular examples are shown in **Fig 29.24**, and their key specifications are shown in **Table 29.2**. Available in outputs ranging from 1 to 5 kW, these generators use one or more of the mechanical regulation systems mentioned previously, but their ultimate benefit comes from the use of a built-in ac-dc-ac inverter system that produces beautiful — if not perfect — 60 Hz sine waves at 120 V ac, with a 1% to 2% tolerance, even under varying load conditions.

Instead of using two windings in the generator core, an inverter generator uses 24 or more windings to produce a high frequency ac waveform of up to 20 kHz. A solid state inverter module converts the high frequency ac to smooth dc, which is in turn converted to clean, tightly regulated 120 V ac power. And that's not all. Most inverter generators are compact, lightweight and quiet.

GENERATOR CONSIDERATIONS

In addition to capacity and output regulation, other factors such as engine type, noise level, fuel options, fuel capacity, run time, size, weight, cost or connector type, may factor in your decision. Consider additional uses for your new generator beyond Field Day or other portable operation.

Capacity

Your generator must be able to safely power all of the devices that will be attached to it. Simply add up the power requirements of *all* the devices, add a reasonable safety margin (25 to 30%) and choose a suitably powerful generator that meets your other requirements.

Some devices — especially electric motors — take a lot more power to start up than they do to keep running. A motor that takes 1000 W to run may take 2000 to 3000 W to start. Many items don't require extra start-up power, but be sure to plan accordingly.

Always plan to have more capacity than you require or, conversely, plan to use less gear than you have capacity for. Running on the ragged edge is bad for your generator *and* your gear. Some generators are somewhat overrated, probably for marketing purposes. Give yourself a margin of safety and don't rely on built-in circuit breakers to save your gear during overloads. When operating at or beyond capacity, a generator's frequency and voltage can vary widely before the current breaker trips.

Size and Weight

Size and weight vary according to power output — low power units are lightweight and physically small, while beefier models are larger, weigh more and probably last longer. Watt for watt, however, most modern units are smaller and lighter than their predecessors. Models suitable for hamming typically weigh between 25 and 125 pounds.

Engines and Fuel

Low end generators are typically powered by low-tolerance, side valve engines of the type found in discount store lawnmowers. They're noisy, need frequent servicing and often die quickly. Better models have overhead valve (OHV) or overhead cam (OHC) engines, pressure lubrication, low oil shutdown, cast iron cylinder sleeves, oil filters, electronic ignition systems and even fuel injection. These features may be overkill for occasional use but desirable for more consistent power needs.

Run Time

Smaller generators usually have smaller gas tanks, but that doesn't necessarily mean they need more frequent refueling. Some small generators are significantly more efficient than their larger counterparts and may run for half a day while powering small loads. As with output power, run times for many units are somewhat exaggerated and are usually specified for 50% loads. If you're running closer to max capacity, your run times may be seriously degraded. The opposite is also true. Typical generators run from three to nine hours on a full tank of gas at a 50% load.

Noise

Except for ham-friendly inverter units — which are eerily quiet thanks to their high tech, sound dampening designs — standard generators are almost always too loud. Noise levels for many models are stated on the box, but try to test them yourself or talk to someone who owns the model you're interested in before buying. Environmental conditions, distance to the generator and the unit's physical orientation can affect perceived noise levels.

Generators housed in special sound dampened compartments in large boats and RVs can be much quieter than typical "outside" models. However, they are expensive and heavy, use more fuel than compact models, and most don't have regulation specs comparable to inverter models.

Regulation

For hams, voltage and frequency regulation are the biggies. AVR units with electronic output regulation (at a minimum) and inverter generators are highly desirable and should be used exclusively, if only for peace of mind.

Unloaded standard generators can put out as much as 160 V ac at 64 Hz. As loads increase, frequency and voltage decrease. Under full load, output values may fall as low as 105 V at 56 Hz. Normal operating conditions are somewhere in between.

Some hams have tried inserting uninterruptible power supplies (UPSs) between the generator and their sensitive gear. These devices are often used to maintain steady, clean ac power for computers and telecommunication equipment. As the mains voltage moves up and down, the UPS's Automatic Voltage Regulation (AVR) system bucks or

boosts accordingly. The unit's internal batteries provide power to the loads if the ac mains (or your generator) go down.

In practice, however, most UPSs can't handle the variation in frequency and voltage of a generator powered system. When fed by a standard generator, most UPSs constantly switch in and out of battery power mode — or don't *ever* switch back to ac power. When the UPS battery goes flat, the unit shuts off. Not *every* UPS and *every* generator lock horns like this, but an inverter generator is a better solution.

DC Output

Some generators have 12 V dc outputs for charging batteries. These range from 2 A trickle chargers to 100 A powerhouses. Typical outputs run about 10 to 15 A. As with the ac outputs, be sure to test the dc outputs for voltage stability (under load if possible) and ripple. Car batteries aren't too fussy about a little ripple in the charging circuit, but your radio might not like it at all!

Miscellaneous

Other considerations include outlets (120 V, 240 V and dc output), circuit breakers (standard or ground fault interrupter type), fuel level gauges, handles (one or two), favorite brands, warranties, starters (pull or electric), wheels, handles or whatever you require.

SETUP, SAFETY AND TESTING

Before starting the engine, read the user manual. Carefully follow the instructions regarding engine oil, throttle and choke settings (if any). Be sure you understand how the unit operates and how to use the receptacles, circuit breakers and connectors.

Make sure the area is clean, dry and unobstructed. Generators should *always* be set up *outdoors*. Do not operate gas powered engines in closed spaces, inside passenger vans, inside covered pickup beds, etc. If rain is a possibility, set up an appropriate canopy or other *outdoor protective structure.* Operating generators and electrical devices in the rain or snow can be dangerous. Keep the generator and any attached cords dry!

Exhaust systems can get hot enough to ignite certain materials. Keep the unit several feet away from buildings, and keep the gas can (and other flammable stuff) at a safe distance. Don't touch hot engines or mufflers!

When refueling, shut down the generator and let things cool off for a few minutes. Don't smoke, and don't spill gasoline onto hot engine parts. A flash fire or explosion may result. Keep a small fire extinguisher nearby. If you refuel at night, use a light source that isn't powered by the generator and can't ignite the gasoline.

Testing

Before starting (or restarting) the engine, *disconnect* all electrical loads. Starting the unit while loads are connected may not damage the generator, but your solid state devices may not be so lucky. After the engine has warmed up and stabilized, test the output voltage (and frequency), if possible, *before* connecting loads.

Because unloaded values may differ from loaded values, be sure to test your generator under load (using high wattage quartz lights or an electric heater as appropriate). Notice that when you turn on a hefty load, your generator will "hunt" a bit as the engine stabilizes. Measure ac voltage and frequency again to see what the power conditions will be like under load. See your unit's user manual or contact the manufacturer if adjustments are required.

Safety Grounds and Field Operation

Before we can connect *real* electrical loads in a Field Day situation we need to choose a grounding method — a real controversy among campers, RVers and home power enthusiasts.

To complicate matters, most generators have ac generator grounds that are connected to their metal frames, but some units do not bond the ac neutral wires to the ac ground wires (as in typical house wiring). Although they will probably safely power your ham station all day long, units with unbonded neutrals may appear defective if tested with a standard ac outlet polarity tester.

Some users religiously drive copper ground rods into the ground or connect the metal frames of their generators to suitable existing grounds, while others vigorously oppose this method and let their generators float with respect to earth ground (arguing that if the generator isn't connected to the earth, you can't complete the path to earth ground with your body should you encounter a bare wire powered by the generator; no path, no shock). Some user manuals insist on the ground connection, while others don't.

You can follow your unit's user manual, check your local electric code, choose a grounding method based on personal preference or expert advice, or do further research. Either method may offer better protection depending on exact circumstances.

Regardless of the grounding method you choose, a few electrical safety rules remain the same. Your extension cords *must* have intact, waterproof insulation, three "prongs" and three wires, and must be sized according to loads and cable runs. Use #14 to #16 AWG, three wire extension cords for low wattage runs of 100 feet or less. For high wattage loads, use heavier #12 AWG, three wire cords designed for air compressors, air conditioners or RV service feeds. If you use long extension cords to power heavy loads, you may damage your generator or your radio gear. When it comes to power cords, think *big*. Try to position extension cords so they won't be tripped over or run over by vehicles. And don't run electrical cords through standing water or over wet, sloppy terrain.

During portable operations, try to let all operators know when the generator will be shut down for refueling so radio and computer gear can be shut down in a civilized manner. Keep the loads disconnected at the generator until the generator has been refueled and restarted.

29.3.2 Portable DC Power Sources

If a generator is not available to supply ac voltage for portable operation, starter or marine deep-cycle batteries are often used for portable or Field Day operation. Battery-only dc operation has its own unique set of problems, not the least of which is voltage stability.

Most solid-state transceivers are designed to operate at a nominal 13.8 V from a battery being charged by a vehicle's engine. Depending on the battery type, resting voltage may be as low as 12.2 V (lead-acid in this case). As the battery's state of charge (SoC) is reduced, so is the voltage, especially under load. (See the **Power Sources** chapter for complete information on batteries, including charging.) As voltage falls, transmit signal quality begins to drop, sometimes drastically, and output power drops off as well. Further, most transceivers will simply shut themselves off once their input voltage drops to approximately 11.6 V. There are two popular workarounds to the problem.

First, multiple batteries wired in parallel may be used to extend operating time. But their terminal voltage when not being charged is still around 12 – 12.2 V, well below what the radio wants to see. Several manufacturers and distributors sell "battery boosters" that provide a regulated output of 13.8 V as battery voltage varies. Booster efficiency varies with the input voltage and current draw, but hovers around 80%.

Another workaround in some cases is a dc-to-dc converter which runs from a nominal input of 24 or 48 V, providing a regulated output of 13.8 V. In this case, two (or more) 12 V batteries are wired in series or in series-parallel to extend operating time. Converter efficiency is typically greater than 88%. Both ground-isolated and non-isolated models are available. The latter units use a common bus for the negative connection between power source batteries and output connections.

Whichever method is used, battery voltage should be monitored to assure long battery

charge-cycle life. For example, a nominal 12 V lead-acid battery is considered 100% discharged when the voltage under load reaches 10.5 V. Below this level the charge-cycle life is reduced. Other battery types have similar SoC (discharge) level ratings.

29.3.3 Portable Antennas

An effective antenna system is essential to all types of operation. Effective portable antennas, however, are more difficult to devise than their fixed-station counterparts. A portable antenna must be light, compact and easy to assemble. It is also important to remember that the portable antenna may be erected at a variety of sites, not all of which will offer ready-made supports. Strive for the best antenna system possible because operations in the field are often restricted to low power by power supply and equipment considerations. Some antennas suitable for portable operation are described in the **Antennas** chapter.

ANTENNA SUPPORTS

While some amateurs have access to a truck or trailer with a portable tower, most are limited to what nature supplies, along with simple push-up masts. Select a portable site that is as high and clear as possible. Elevation is especially important if your operation involves VHF. Trees, buildings, flagpoles, telephone poles and the like can be pressed into service to support wire antennas. Drooping dipoles are often chosen over horizontal dipoles because they require only one support.

An aluminum extension ladder makes an effective antenna support, as shown in **Fig 29.25**. In this installation, a mast, rotator and beam are attached to the top of the second ladder section with the ladder near the ground. The ladder is then pushed vertical and the lower set of guy wires attached to the guy anchors. When the first set of guy wires is secured, the ladder may be extended and the top guy wires attached to the anchors. Do not attempt to climb a guyed ladder.

Fig 29.26 — Telescoping fiberglass poles can be used to support a variety of wire antennas or small VHF/UHF Yagis. This one is 40 feet long, yet collapses to 8 feet for storage.

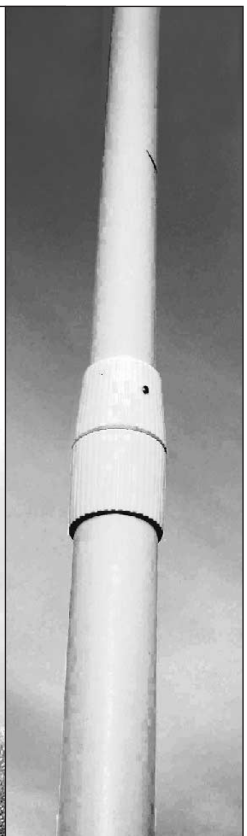

Fig 29.27 — Close-up of a telescoping mast. Sections slide together and are secured by twisting a locking mechanism.

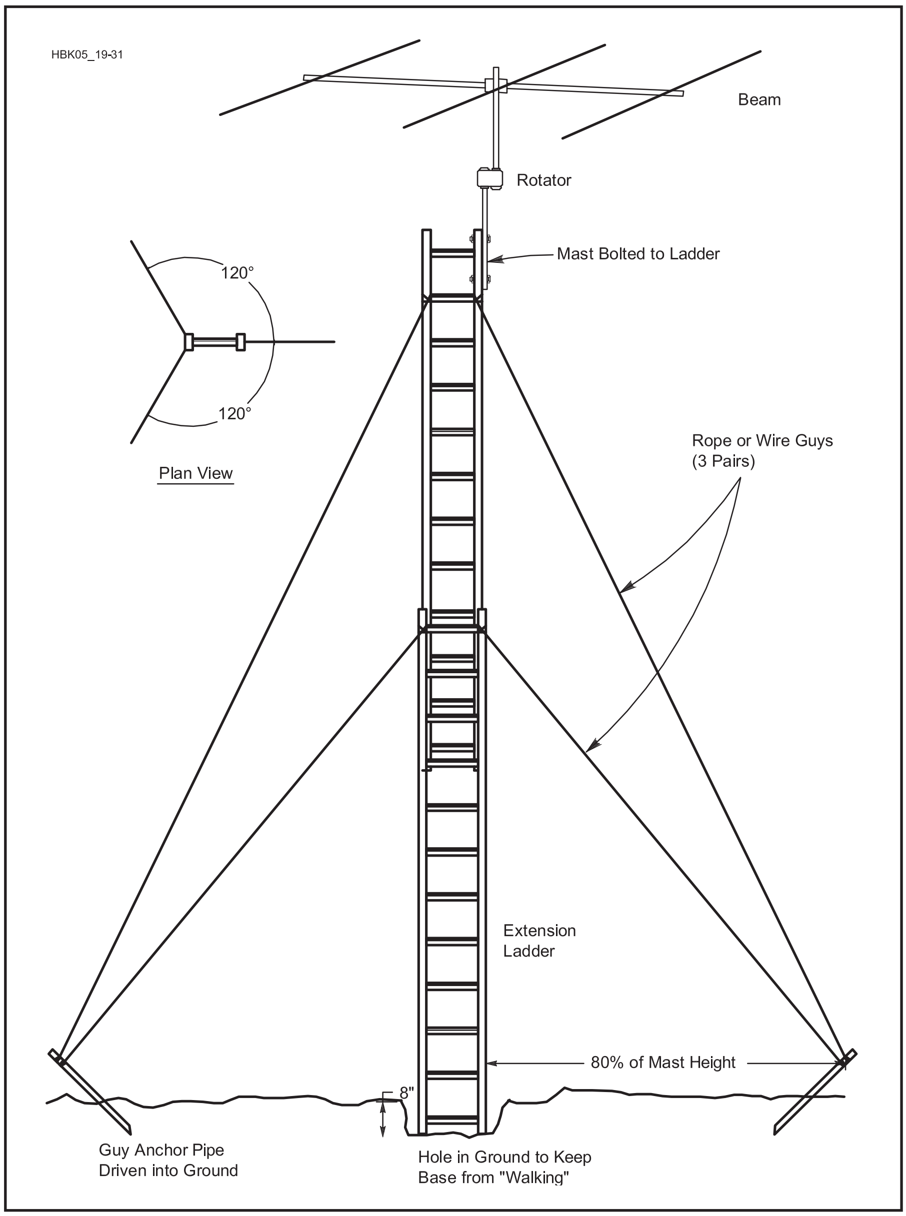

Fig 29.25 — An aluminum extension ladder makes a simple but sturdy portable antenna support. Attach the antenna and feed lines to the top ladder section while it is nested and lying on the ground. Push the ladder vertical, attach the bottom guys and extend the ladder. Attach the top guys. Do not attempt to climb this type of antenna support.

(B)

(A)

Fig 29.28 — The portable tower mounting system by WA7LYI. At A, a truck is "parked" on the homemade base plate to weigh it down. At B, the antennas, mast and rotator are mounted before the tower is pushed up. Do not attempt to climb a temporary tower installation.

Telescoping fiberglass poles (**Figs 29.26** and **29.27**) are popular for supporting wire verticals, inverted Vs and small VHF/UHF antennas. These poles can extend up to 40 feet in length, yet retract to 4 to 8 feet for easy transport. They typically weigh less than 20 pounds, and some are much lighter.

Figs 29.28 and **29.29** illustrate two methods for mounting portable antennas described by Terry Wilkinson, WA7LYI. Although the antennas shown are used for VHF work, the same principles can be applied to small HF beams as well.

In Fig 29.28A, a 3 foot section of Rohn 25 tower is welded to a pair of large hinges, which in turn are welded to a steel plate measuring approximately 18 × 30 inches. One of the rear wheels of a pickup truck is "parked" on the plate, ensuring that it will not move. In Fig 29.28B, quad array antennas for 144 and 222 MHz are mounted on a Rohn 25 top section, complete with rotator and feed lines. The tower is then pushed up into place using the hinges, and guy ropes, anchored to heavy-duty stakes driven into the ground, complete the installation. This method of portable tower installation offers an exceptionally easy-to-erect, yet sturdy, antenna support. Towers installed in this manner may be 30 or 40 feet high; the limiting factor is the number of "pushers" and "rope pullers" needed to get into the air. A portable station located in the bed of the pickup truck completes the installation.

The second method of mounting portable beams described by WA7LYI is shown in Fig 29.29. This support is intended for use with small or medium-sized VHF and UHF arrays. The tripod is available from any dealer selling television antennas; tripods of this type are usually mounted on the roof of a house. Open the tripod to its full size and drive a pipe into the ground at each leg. Use a hose clamp or small U-bolt to anchor each leg to its pipe.

The rotator mount is made from a 6-inch-long section of 1.5-inch-diameter pipe welded to the center of an "X" made from two 2-foot-long pieces of concrete reinforcing

(A) (B) (C)

Fig 29.29 — The portable mast and tripod by WA7LYI. At A, the tripod is clamped to stakes driven into the ground. The rotator is attached to a homemade pipe mount. At B, rocks piled on the rotator must keep the rotator from twisting and add weight to stabilize the mast. At C, a 10 foot mast is inserted into the tripod/rotator base assembly. Four 432 MHz Quagis are mounted at the top.

rod (rebar). The rotator clamps onto the pipe, and the whole assembly is placed in the center of the tripod. Large rocks placed on the rebar hold the rotator in place, and the antennas are mounted on a 10 or 15 foot tall mast section. This system is easy to make and set up.

TIPS FOR PORTABLE ANTENNAS

Any of the antennas described in the **Antennas** chapter or available from commercial manufacturers may be used for portable operation. Generally, though, big or heavy antennas should be passed over in favor of smaller arrays. The couple of decibels of gain a 5-element, 20 meter beam may have over a 3-element version is insignificant compared to the mechanical considerations. Stick with arrays of reasonable size that are easily assembled.

Wire antennas should be cut to size and tuned prior to their use in the field. Be careful when coiling these antennas for transport, or you may end up with a tangled mess when you need an antenna in a hurry. The coaxial cable should be attached to the center insulator with a connector for speed in assembly. Use RG-58 for the low bands and RG-8X for higher-band antennas. Although these cables exhibit higher loss than standard RG-8, they are far more compact and weigh much less for a given length.

Beam antennas should be assembled and tested before taking them afield. Break the beam into as few pieces as necessary for transportation and mark each joint for speed in reassembly. Hex nuts can be replaced with wing nuts to reduce the number of tools necessary.

29.4 Remote Stations

The following section was contributed by Rick Hilding, K6VVA. Rick has constructed his own competitive remote HF contest station and presents issues for the remote station builder to consider. He also wishes to acknowledge the assistance and input of N6RK, K6TU, W6OOL and SM2O. Although this section focuses on "remoting" HF equipment, the same considerations apply to most remotely-operated stations, with the exception of repeater installations. For the purposes of this section, "remote station" applies to individually-operated stations, primarily using SSB, CW, and digital modes on the HF bands. Many of the same techniques and considerations apply to weak-signal remote operation on the VHF and UHF bands.

29.4.1 Introduction

Remote stations (stations operated by remote control) have been a part of Amateur Radio for decades, but usually in the form of VHF/UHF repeaters. In the past, a few remote stations operating on HF have been developed in impressive locations with significantly more land, equipment and expense than for a repeater installation. Prior to the expansion of Internet technologies, some of these remote pioneers utilized VHF/UHF links or commercial microwave equipment for connectivity between the remote and home stations. There has been a significant increase in the number of remote stations over the last five years and the trend is accelerating rapidly.

Since this section was first added in the 2011 edition, there have been several new developments and refinements of the technology available to remote station builders. As latency across the Internet has been reduced, operating in fast-paced contests over very long links is now commonplace — between the US and Japan, Finland and South Korea, and other similar spans. More than 4500 QSOs were made by OH2UA operating remotely as CQ8X in the Azores.

Local homeowner restrictions on antennas and interference issues from electrical power lines, plasma TVs, network routers and the like increasingly encumber HF operating. This is quite a turnabout from the days of amateur signals causing TVI! With today's technology, however, a remote HF station far from these problems may be as simple as a 100-W HF radio and all-band dipole or vertical with connectivity to the operator via the Internet. There is a flavor of remote station to meet almost every taste and budget.

This overview of remote station construction looks at three aspects of the project: planning the facilities, connectivity and remote station equipment. All three are equally important for a successful project and will be different for each installation. There is no cookbook approach to creating a remote station, so this discussion is intended to introduce topics that must be considered in the circumstances encountered by each station builder.

29.4.2 Evaluation and Planning

OPERATING REQUIREMENTS

Will your remote station be only for remote control from a home QTH or other single control point? Will it serve a dual purpose so you (and possibly others) can also operate at the remote site during favorable conditions? It is important to adequately plan physical space requirements for equipment and operator needs.

Is your remote station to be only for casual operating or will it be used for competitive contesting and DXing? If the latter, then the issue of *latency* (described below) will be much more significant.

Are you interested in operating on all HF bands including 60, 30, 17 and 12 meters? Will you operate on both CW and SSB? Digital modes? Remember that on the low bands, you may need to deal with the SWR variations of an antenna across an entire band.

Will your remote station be low power with a single transceiver or do you want to also use an amplifier? If you're planning a competitive SO2R (single operator, two radio) HF contest station, your needs are going to be much more complex, involving band decoders, automatic dual-radio and antenna switching mechanisms and the like.

Do you plan to use a single multiband antenna, or maybe a tribander and wire antennas for the low bands, or are you planning to install the "Mother of all Antenna Farms"? Make sure you have enough physical space available at the intended site.

PURCHASE VS RENT OR LEASE

If you don't already own or have the funds to purchase the property for your remote site, there is still hope! Although having direct control over every aspect of what you want to do is most desirable, you may want to consider a rental or lease with a cooperative land owner. In either case, having a detailed agreement or contract prepared by a competent attorney is a must. Be sure to include every contingency you can think of, and especially what happens if the land owner decides to sell.

RELIABLE ACCESS BY ROAD

This is one of the most important things to consider in any remote site selection. Will you be able to get there safely, rain or shine? What happens if any problems develop that require immediate attention at the remote site? Pavement or a good all-weather, well-maintained gravel road should be available. Having more than one means of getting in or out should emergencies arise while you are at the site is also an important consideration. These concerns must be addressed before agreeing to purchase, rent or lease a remote site.

GEOLOGICAL AND OTHER HAZARDS

Evaluate the geological factors involved. In a hilltop or mountaintop site, is there evidence of soil movement that could affect access

or damage your equipment shelter or tower installations? Does the property sit near an earthquake fault? Is there a significant risk of fire during fire season? Is the site exposed to high wind or storms? In flat-land sites, is there a risk of flooding or drainage problems? Remember, you won't be there to rescue your equipment! In consideration of both your initial construction activities and ongoing maintenance tasks, are there any wildlife hazards from animals or insects? What about allergies or reactions to plants such as poison ivy or poison oak? Diligently investigate all aspects of a potential remote site *before* you end up with bad surprises down the line. For a reasonable fee, there are companies from which you can secure a Geological and Property Hazards report to aid in your assessment.

RAW SITE PREPARATION

It you are fortunate enough to locate suitable property, be sure to evaluate the site preparation needs. How much time and money will be necessary to develop the remote site to meet your specific needs? Is there brush and vegetation to be dispensed with? Will trees need to be cut down? Will bulldozers, excavators and trenchers need access to the site? Cement trucks? Service vehicles? Diligent evaluation of all costs involved will reduce unnecessary stress.

SITES WITH EXISTING FACILITIES

Finding a site with a self-supporting tower or two in place that can accommodate your needs, along with a building large enough for your equipment and operational needs can be like finding a pot of remote gold. However, unless you are experienced with towers and construction, hire professionals to evaluate everything. If you are considering co-locating at a remote site with existing antennas and equipment in use, consider hiring a professional to help you evaluate the likelihood of problems. Birdies and intermodulation could end up being a source of potential conflict and stress if problems can't be resolved.

TERRAIN CONSIDERATIONS

Evaluate the terrain on the bands you wish to operate. For HF, Dean Straw, N6BV, has developed a very useful program called *HFTA* (*High Frequency Terrain Assessment*) that is included with the *ARRL Antenna Book*, of which he is a former editor. Use *HFTA* to assist you in placement of your antennas. Don't expect excellent ground/soil conductivity if your remote site is on top of a rocky mountaintop.

If you plan to use vertical antennas, make sure there is sufficient room on the property to place the radials, whether on a mountaintop or flat area. Placing verticals near water, especially saltwater, is the most desirable way to achieve the low takeoff angles for long-haul DX. Remember that exposure to salt air or spray will create significant maintenance issues.

NOISE LEVELS

Since one of the reasons for building a remote station is to lower noise levels, you'll want to carefully evaluate existing and potential noise sources. Start by visiting the site with a receiver in several different types of weather and listening on all the bands you intend to use with a full-size dipole antenna. If noise levels are low, this is no guarantee that problems won't crop up in different seasons or from hardware failures. You should avoid nearby substations or high-voltage and power distribution lines. If you will be sharing a site with other users, see the discussion below on noise and interference from and to their equipment.

TELEPHONE OR INTERNET ACCESS

If you are planning to operate your remote station via the Internet, having suitable telephone line access is required unless wireless Internet service is available. Be sure that broadband service such as DSL or cable TV can reach your site by asking the local service provider to do a site evaluation. Satellite Internet downlink speed may be fast, but uplink speed is often quite a bit slower. Be sure the minimum link speed is adequate in both directions.

If your control point is close enough to the remote site, another option is to implement your own private wireless "bridge" system. Even if multiple "hops" are involved, with the right equipment you can potentially have better results than using even broadband Internet.

The author has achieved a low 1 ms latency by using a dedicated point-to-point 5 GHz wireless link between his home QTH and the remote station site on a mountain ridge 4.4 miles away. Each remote link will have different results.

ELECTRICAL POWER

Having electrical power already available at your remote site can certainly save a lot of money. The most ideal situation is to have underground power to the remote site. Be sure to evaluate the full costs of installing ac power if it is not already present at the site or on the property. Truly remote sites may require wind, solar or generator power systems like that shown in **Fig 29.30**.

If your remote site will require solar/wind/battery power, it is critical that you properly assess sunlight path and duration, wind patterns, and provide sufficient battery storage to meet your intended operating needs during lengthy periods of inclement weather. The article "Designing Solar Power System

Fig 29.30 — Solar panels can be used to charge a bank of batteries to supply power. Effective off-grid power requires an accurate and conservative estimate of power needs and available energy sources. [Rick Hilding, K6VVA, photo]

for FM Translators" is a valuable resource for planning of remote HF station off-grid power.[1] You must thoroughly account for the power requirements of each and every piece of equipment.

There are various estimates for the duty cycle of transceivers. A conservative duty cycle of 50% for CW/SSB is recommended for power capacity evaluation. (RTTY/digital/AM/FM duty cycles will likely be higher.) Internet switches, routers, rotators, computers and anything electrical will also consume power. A supplementary diesel or propane remote-start generator to a basic off-grid system may be an appropriate option, particularly if you plan on using an amplifier. If your remote site is in a rugged terrain rural area, make sure a diesel or propane service provider vehicle can get to the location *before* you make final plans! It may be possible to use smaller propane tanks you can haul in a truck, but any manifold-type system necessitates insuring that the proper BTU requirements can be met based upon the propane generator manufacturer's ratings. Installing a solar and wind remote battery monitor system is advisable.

When you have made an accurate assessment of your complete system needs, add a generous additional contingency factor. It is also advisable to get quotes on your proposed system from at least two different "green power" equipment suppliers, and to make sure they fully understand your requirements and intended use *before* you purchase anything.

INSURANCE AND SECURITY

You've heard the expression "Stuff Happens." Unless you have blanket coverage in an existing homeowner's insurance policy that includes your remote site equipment, look into the ARRL "All-Risk" Ham Radio Equipment Insurance Plan. If you will be hiring others to do work at your remote site, be sure that liability coverage issues are addressed. The same applies to any guests or visitors such as fellow hams. Have a competent attorney draw up a "Liability Release" agreement with strong "Hold Harmless" language.

If your remote site is yours alone and not a co-habitation arrangement with other services, be sure and evaluate all security needs (a necessity even if co-located). You might need one or more security gates, webcam surveillance and auto-remote notification of security breaches.

PERSONAL SAFETY

Regardless of your age, it is prudent to have someone with you at the site. You could severely cut yourself, or fall and break a leg. If there are wildlife hazards in the area, take appropriate steps to protect yourself.

Carry a first aid kit and have one readily available at your remote site. Keep some emergency supplies such as various sealed food items in a varmint-proof container and a case of bottled water in the event you find yourself stranded.

If your remote site is within the coverage area of a local repeater, take along a handheld radio (with batteries charged) as part of your SOP (Standard Operating Procedure). This is especially important for rural and remote operating sites.

29.4.3 Controlling Your Remote Site HF Station

Almost any modern all-mode transceiver can be controlled remotely by software. Several packages are listed in the Remote Station Resource document on the CD-ROM

Licenses and Remote Operation

Operating a remote station also carries with it an extra responsibility to be properly licensed and to identify your station correctly. Because the transmissions are made from the location of the remote station, you must follow the regulations that apply at the remote location. This is particularly important when the station is outside the jurisdiction of the regulatory authority that granted your license, such as a US ham operating a station in South America or a European ham operating a station in the US. You must be properly licensed to transmit from the remote station! This may require a separate license or reciprocal operating permission from the country where the remote station is located. Don't assume that because you have a US license, you automatically have a corresponding license to operate a remote station outside the US. For instance, CEPT agreements generally do not apply to operators who are not physically present at the transmitter. There may also be contest or award rules that apply to remote stations — be sure to know and follow all rules that apply.

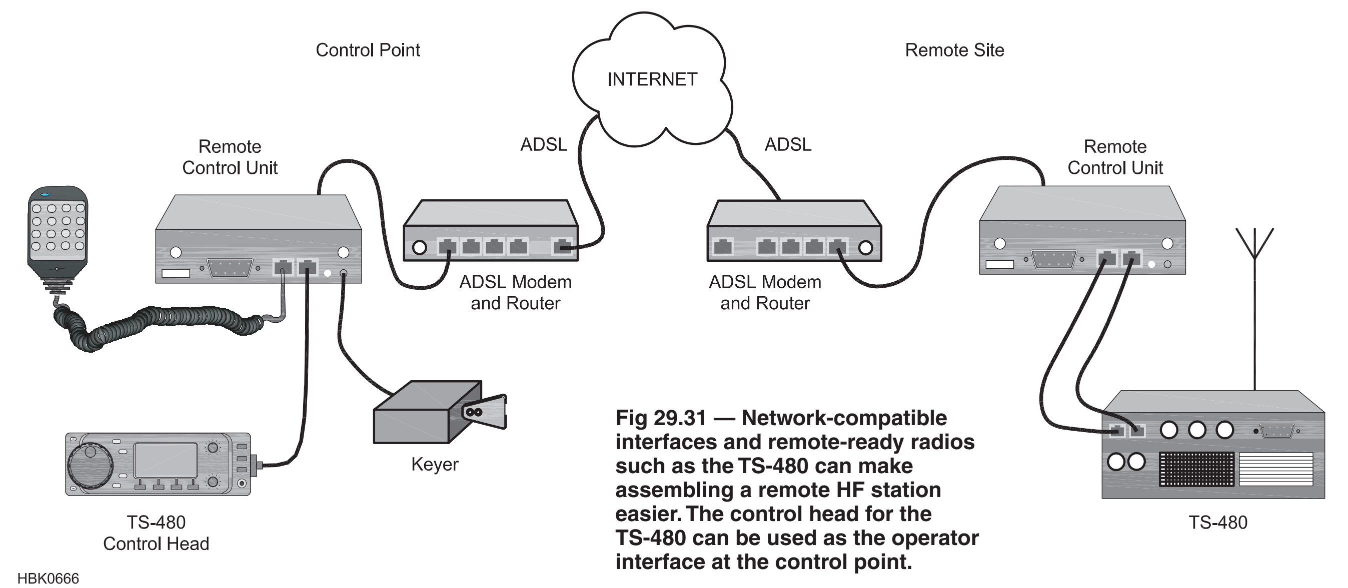

Fig 29.31 — Network-compatible interfaces and remote-ready radios such as the TS-480 can make assembling a remote HF station easier. The control head for the TS-480 can be used as the operator interface at the control point.

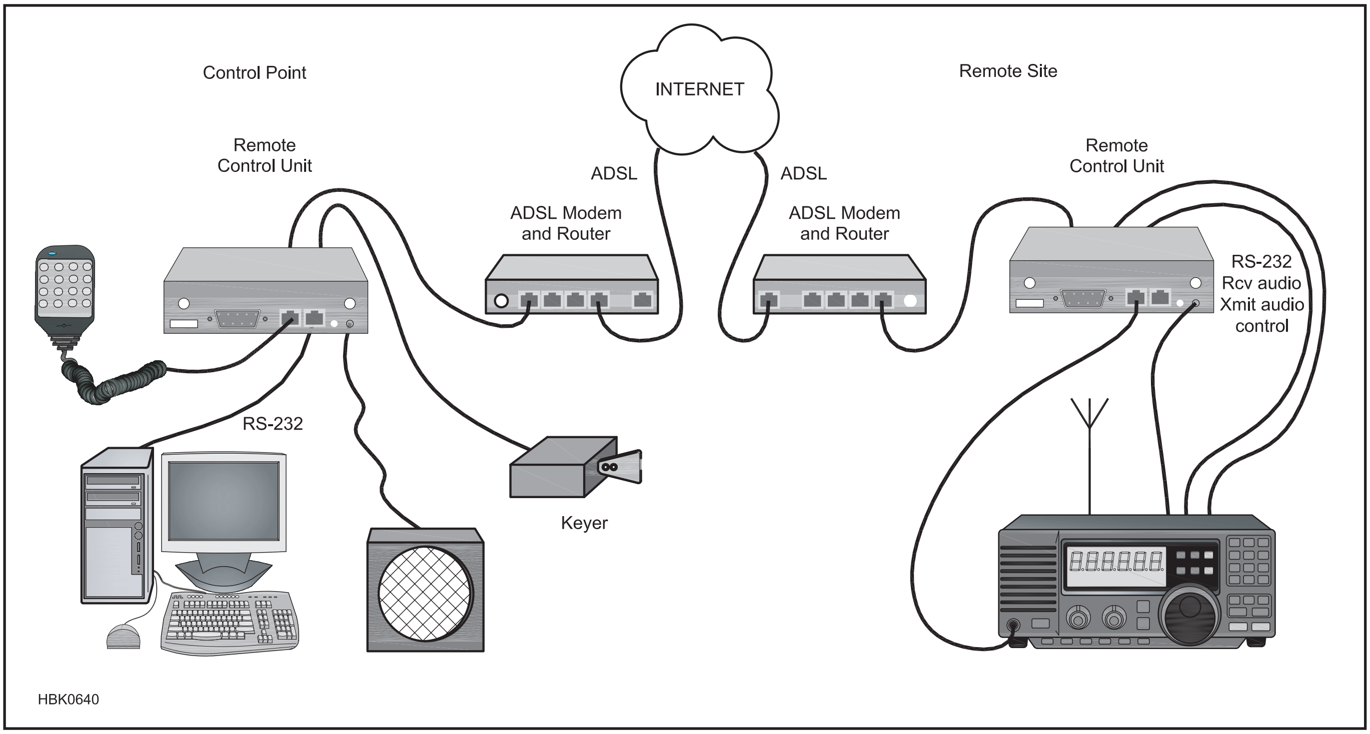

Fig 29.32 — Radios without network connectivity can be controlled by using an RS-232 interface at the remote site. A computer running control software at the control point forms the operator interface.

included with this book. (The resource listing also includes vendors of remote control interface equipment.) The manufacturer of your radio may also offer remote control software.

Fig 29.31 illustrates the design of a basic remote HF station system which uses Remoterig control interfaces.[2] ADSL is used to connect the interfaces via the Internet. A suitable radio, microphone and CW paddle are connected to the interface on each end. The Kenwood TS-480 radio in the figure is designed for simple connectivity to a network-style interface. Other radios may require an RS-232 interface as shown in **Fig 29.32**. The radio in this system is located entirely at the remote site and a computer running control software creates the operator's interface at the control point.

A popular alternative for contesters and DXers is to run the contest/logging software on a computer at the remote site with a Winkey CW keyer to generate CW under software control. *Windows XP Pro* has self-contained server capabilities for *Windows* Remote Desktop, and the WinRDP client can be used for access from the control point computer. For *Windows XP Home* operating systems, VNC (Virtual Network Computing — **http://en.wikipedia.org/wiki/Virtual_Network_Computing**) utility software is available from several companies. For later versions of *Windows*, similar remote desktop user control software is available.

CONNECTING TO YOUR REMOTE SITE HF STATION

The most common way of connecting to a remote site station is via the Internet. You will want to learn computer networking basics, find a ham friend with the necessary skills, or hire a computer networking consultant to help you. Terms like IP addresses, routers, port forwarding, DMZ, bandwidth, latency and others found in the Remote Station Glossary at the end of this chapter will become very familiar. A convenient list of other computer network terms can be found online at **www.onlinecomputertips.com/networking/terminology.html**.

If your remote site has no telephone or Internet service and you have a line-of-sight path between your home and the site, one logical choice for connectivity is to use a pair of wireless network bridge units and a pair of netbook computers with solid state drives (SSD) and low power consumption. **Fig 29.33** shows an example of Airaya 5 GHz wireless bridges and ASUS Eee PC netbook computers. The NanoBridge M5 wireless system from Ubiquiti Networks (**www.ubnt.com**) is

Fig 29.33 — Solid-state disk drives in netbook-style computers and wireless point-to-point Ethernet bridges can be used to form a low-power, high-reliability computer-to-computer control link.

another option for this form of connectivity.

If a direct line of site doesn't exist, multiple bridge units can be used to overcome various terrain challenges. Of course, overall latency will increase somewhat and the additional locations require a power source to operate the units. A word of caution about using unlicensed equipment and spectrum — you run the risk of potential interference from other users on the band.

UNDERSTANDING INTERNET LATENCY

High latency can seriously impair the usability of your remote station. For casual operating, you may be able to tolerate a latency of 250 ms or 300 ms. Serious contesters and DXers will most likely find this much delay frustrating, especially on CW. If you are a high-speed CW contest operator, a very low latency is required to be competitive.

ASSESSING LATENCY

You can easily evaluate basic Internet latency yourself. In a *Windows* (PC) environment, under Start|All Programs|Accessories you will find Command Prompt. From within this DOS-like window you can run the *ping*, *tracert* and or *pathping* commands to access a particular IP address and measure the latency. This is critical to know in advance or to troubleshoot connectivity issues once you are operational.

For the purposes of conducting Internet system audio latency tests, N6RK's method illustrated as a block diagram in **Fig 29.34** is very effective. Using a receiver at the remote site and one at the control point, the recorded latency can easily be determined. **Fig 29.35** shows a latency of 40 ms for the return audio over K6VVA's private control link using a Remoterig audio quality setting that requires a network speed of about 180 kbps. The audio is crystal clear and at 40 ms, little difference is noticed from having the TS-480 control head connected directly to the radio at home.

ESTIMATING INTERNET BANDWIDTH REQUIREMENTS

It is important to have a good idea of the actual bandwidth requirements for the effective operation of your remote HF station via the Internet. The higher the quality of the audio you need, the higher the bandwidth required. Unless you plan to use a private wireless bridge link, Internet speeds will determine your available bandwidth. Many remote station operators have found Skype (**www.skype.com**) a workable solution for remote audio routing as well as IP SOUND (**http://ip-sound.software.informer.com**). Another way to completely avoid Internet latency and bandwidth issues for audio is to use POTS (Plain Old Telephone System) connectivity with a dedicated analog phone line that might also be shared with a DSL data service.

Sharing an Internet connection can also cause reduction in bandwidth. If others in your home are online at the same time, their activity will reduce bandwidth available to you. A dedicated line or service upgrade to support remote station operation may be required unless you can account for all the concurrent household bandwidth requirements and determine that your service is capable of handling it all. A router with "QoS" (quality of service) prioritizing capabilities might solve or at least minimize some of the multi-user problems on a single line Internet connection.

CW and SSB do not pose the same the bandwidth problems as RTTY, unless pan-adapter/waterfall type displays are used. If

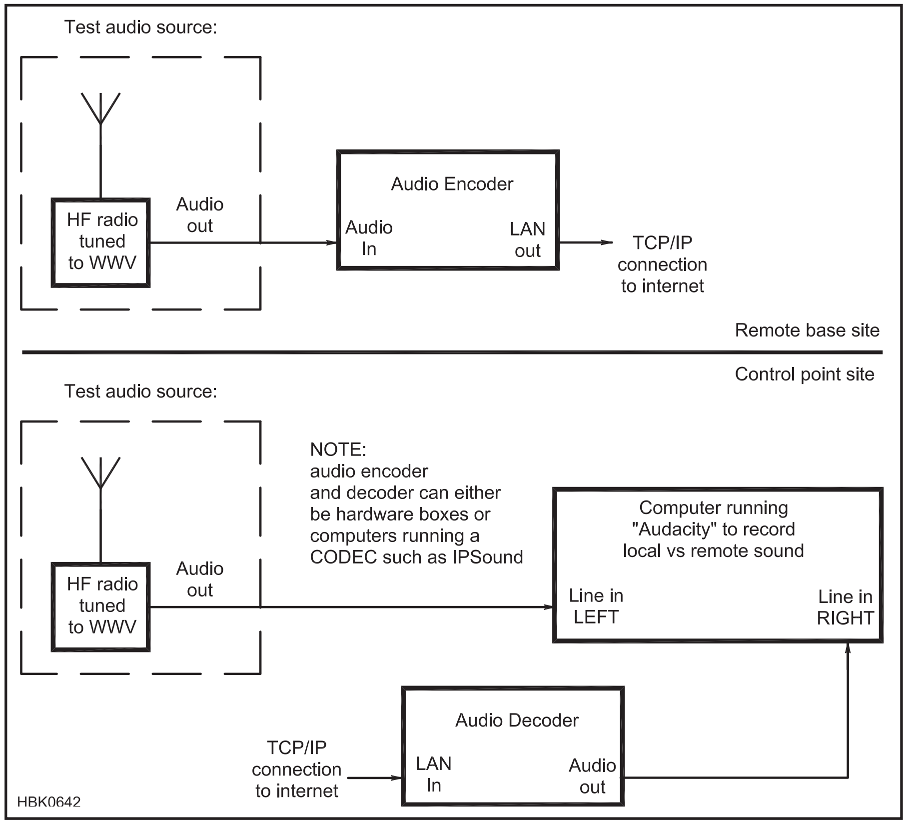

Fig 29.34 — By listening to a distant radio station at both the remote site and the control point, the delay in received audio from the remote site determines latency between the sites. (System design by N6RK.)

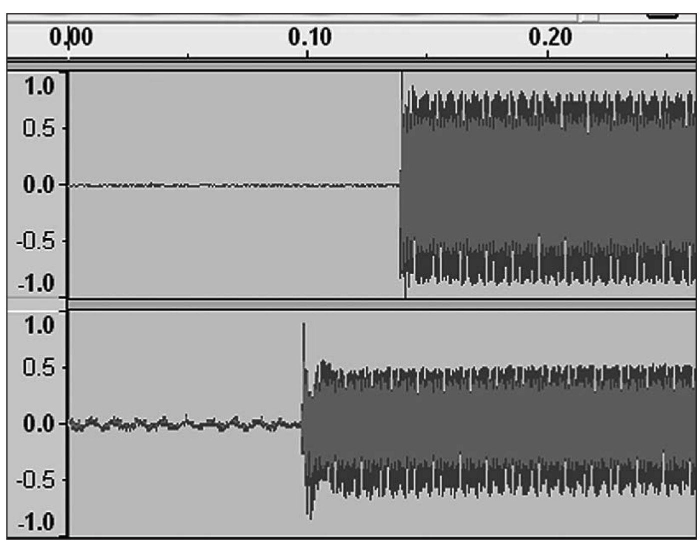

Fig 29.35 — The recordings of audio recorded from the remote site link and from the local receiver clearly show the estimated 40 ms of latency.

you plan to use a webcam or two for monitoring and security purposes, you must account for that bandwidth in your overall connectivity planning as well. Remember that screen changes of any type consume bandwidth.

29.4.4 A Basic Remote HF Station

There are several ways to approach implementing a remote HF station. One path is to start small with a single transceiver and a multi-band dipole, vertical and/or tribander. You can be up and running while working on your long-range plan. (A remote VHF/UHF station has a similar structure.)

K6VVA's SO2R (single-operator, two radio) remote station began with a single Kenwood TS-480 using W4MQ IRT system cables and hardware, LDG AT-200PRO tuner, a refurbished TH3, Jr. tribander on a 27-foot mast and a Carolina Windom 160. The ASUS Eee PC with *Windows XP Pro* enabled use of the *Windows* Remote Desktop server and also contained the *TR4W* contest logging software which generated CW via a Winkey keyer. The initial equipment placement was in a small used camper which also housed the solar-power storage batteries in plastic battery cases, and the Airaya wireless bridge with a small panel antenna mounted on the back of the camper. (You can see some of this equipment in **Fig 29.36**.)

The most significant improvement was made by adding Remoterig interfaces by SM2O (**www.remoterig.com**). While still located inside the small camper, the station was expanded to a functional SO2R operation using two Remoterig units and two TS-480 transceivers. The increase in audio quality at a low latency was significant.

Over time, the remote station grew to include a larger Tuff Shed mini-barn with interior alterations to provide for a separate battery and power system room, an interior operating "shack" with view window of a nearby reservoir and custom built-in operating desk, as well as an overhead sleeping loft and front entry area. The final build-out of this remote station has evolved into what seems like a never ending work-in-progress. More time and money has been expended on road repairs than in completing the final desired station. One thing to always keep in mind is that things "always take longer than expected, and always cost more than expected."

MURPHY'S LAW FOR REMOTE HF STATIONS

Murphy seems to visit remote stations more than home QTH stations. Plan on it. Don't be scared, but rather be prepared! A must for your remote site station is at least one fire extinguisher and regular checks that it is fully charged and ready for use. Remember to include adequate station grounding and lightning protection in your remote station planning!

Troubleshooting remote station problems will present more challenges in general. It would be nice to have backup redundancy for everything at the remote site (including radios, amplifiers, and the like), but for most this will not be practical. If you start out with quality equipment, new coax and cables, and invest with long term thinking in mind, you'll avoid creating the opportunity for problems.

When strange glitches occur while you are on-air, first take a look at your latency and bandwidth to see if there are any issues which have developed in the main connectivity pipeline. In the author's case, trees on neighboring property had grown into the path of the microwave link. Fortunately, he was able to secure permission of that property owner to trim the foliage out of the way.

29.4.5 Remote HF Station Resources

There is no current "Bank of Remote HF" from which to make immediate withdrawals, however you may find the Remote Operating email reflector to be a helpful resource (**http://mailman.qth.net/mailman/listinfo/remoteoperating**). The ARRL has also published *Remote Operating for Amateur Radio*, a book on remote stations.[3]

For this edition there a few new items especially worthy of mentioning. One is a small serial device driver by Moxa (**www.moxa.com**). About the size of a packet of cigarettes, this compact unit has a built in web server, surge protection, and requires 1 W of power for operation which makes it very suitable for sites powered by solar panels and/or batteries. It is also available in multi-port configurations. **Fig 29.37** shows the single-port version.

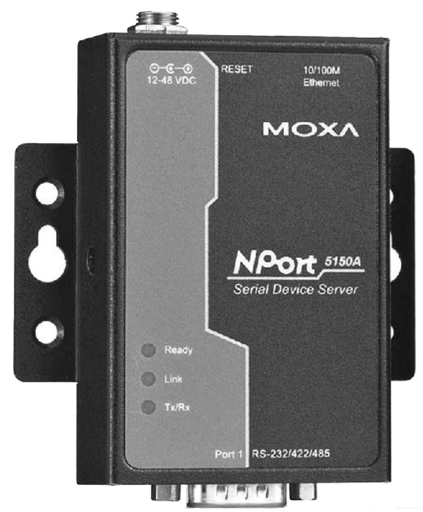

Fig 29.37 — The very small Moxa single-port interface is about the size of a pack of cigarettes.

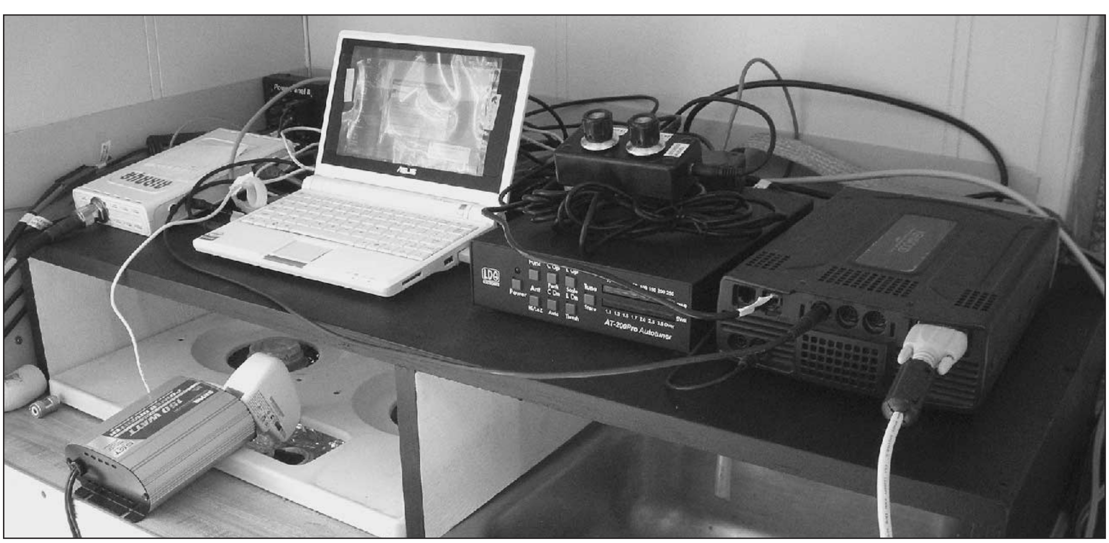

Fig 29.36 — The initial K6VVA remote station

For remote rotator control, the author recommends *PSTRotatorAZ* by Codrut, YO3DMU (**www.qsl.net/yo3dmu**). The software provides for a direct TCP/IP interface, which is used in conjunction with the Moxa serial device driver units for each remote rotator. Rotor-EZ boards from Idiom Press (**www.idiompress.com**) in the Hy-Gain rotator controllers are compatible with *PSTRotatorAZ*. A screenshot of the display taken prior to final configuration of the handy PRESETS buttons is shown in **Fig 29.38**.

Fig 29.38 — Screen display of the *PSTRotatorAZ* remote rotator control panel.

The Elecraft K3 100 W HF transceiver has also been adapted for remote stations. Utilizing the Remoterig interface, the latest K3 firmware supports a "K3 Twin Concept" that allows a regular K3 to be remotely controlled either by a complete K3 in "terminal" mode or a K3/0 (a lower cost K3 without RF components) at the operator control point with no PC required on either end of the link (see **www.elecraft.com/K3-Remote/k3_remote.htm**). **Fig 29.39** shows the combination of a K3 on the left and K3/0 on the right with the Remoterig interfaces. Flexradio's SDR transceivers (**www.flexradio.com**) are also well-suited to use in remote HF stations — see the **HF Transceiver Survey** on the CD-ROM accompanying this book.

Fig 29.39 — Elecraft K3 Twin Concept system utilizing Remoterig by SM2O.

For those interested in controlling their remote HF stations while mobile, some interesting new options are now available or in development for Apple iOS devices. The Pignology/Etherpig products support control of transceivers and contact logging. CommCat has released a mobile application for iOS devices and their iPhone version is shown in **Fig 29.40**.

Fig 29.40 — CommCat Mobile iPhone application for remote HF station control.

The most capable product for providing "hands on" rig control of a remote station remains the Remoterig by SM2O. The latest RRC-MKII version Control Point unit displayed at the top of **Fig 29.41** includes a built-in CW keyer with potentiometer for speed control. The unit shown at the bottom of the figure is used at the remote station location. The author reports that his original Remoterig units have performed flawlessly for more than four years without incident.

Fig 29.41 — Remoterig by SM2O, the remote HF station control device assessed as having the best performance by the author.

It is predicted that the number of remote station installations will continue to increase dramatically. In particular, as more hams move to the antenna-restrictive environments of retirement and assisted living communities, remote stations offer continued activity, especially on the HF bands.

Although certainly not a complete list, the CD-ROM included with this book includes a listing for vendors of software and equipment mentioned in this section. Don't forget to do an Internet search for "Remote HF Stations," "Remote Base" and derivations thereof. You never know what might show up! By the time this edition appears in print,

there will no doubt be a number of new items available for this rapidly expanding area of station design.

29.4.6 Remote Station Glossary

ADSL — Asymmetric Digital Subscriber Line. A common form of Internet connectivity which also allows for subscriber telephone use at the same time.

Band decoder — An interface device that reads frequency data from a modern transceiver and facilitates automatic control switching of other equipment such as an HF amplifier.

Bandwidth — Typically expressed in Mbps or kbps, this is used to represent both the capability of an Internet connection for data transfer as well as the amount of data to be transferred.

Charge controller — In solar and wind power generation, this device also serves as a regular to prevent overcharging of storage batteries.

Control point — Wherever the operator will be controlling the *remote site* station. This will normally be a home QTH, but could be anywhere connectivity to the remote site is available.

DHCP — Dynamic Host Configuration Protocol. This functionality is incorporated into most routers and provides automatic assignment of IP addresses to computer devices on a LAN where fixed or static IP addresses are not required.

Duty cycle — A device which is constantly "On" would normally be considered to have a 100% duty cycle. Morse code keying has spaces between the elements and the characters, therefore the duty cycle would be considerably less.

Firewall — Hardware or software capabilities in computers and routers which can be configured to minimize or completely block unauthorized users from access.

IP address — Every computer or device accessible via the Internet or a LAN has a unique numeric address, such as 192.168.1.1.

kbps — Kilobits per second (one thousand bits per second). Typically used as a reference to bandwidth data rate capability or actual usage.

LAN — Local Area Network. A home LAN enables multiple computers to connect to a single Internet service.

Latency — The delays involved in data routing from one point to another, but also a factor in A/D conversion processes.

Liability release — A written document to release one party or entity from getting sued in the event of injury.

Manifold — For propane generators, a distribution system which enables the use of multiple smaller tanks instead of one large tank.

Mbps — Megabits per second (one million bits per second). Typically used as a reference to bandwidth data rate capability or actual usage.

ms — Milliseconds. The unit of time typically used for measuring latency.

Netbook — A new generation of portable computers smaller than a traditional laptop or notebook variety. Many netbooks now use solid-state instead of rotating hard drives.

Off-grid — Generally refers to living off a main electrical power grid, but is also synonymous with extremely rugged, rural remote HF station locations at which solar/wind/battery and/or remote start gas/diesel/propane power must be used.

Packet — A formatted set of digital information. All information sent via the Internet is first converted into packets for transmission.

Pathping — A hybrid utility of the *path* and *tracert* functions which requires more time for analysis between two Internet connection points, but results in a more detailed analysis.

Ping — A utility used to ascertain the availability of another computer device over the Internet or LAN and also measure the round trip time required for the connection.

Port forwarding — Functionality most commonly used in routers to direct or re-direct incoming Internet traffic to specific destinations on a local network or LAN.

POTS — Plain Old Telephone Service. This generally refers to the use of a regular analog telephone system for purposes of remote audio and control signal routing in lieu of the Internet.

Remote site — The actual physical location of the transmitter, antennas and related equipment necessary to generate an RF signal on the HF bands. Some have used the term *Remote Base*.

Router — A device which allows traffic on a single Internet service line to be selectively distributed to multiple computer devices on a LAN. Many routers provide for assignment of local IP addresses as well as automatically via DHCP.

Smartphone — A generic term for the new generation of portable phones with integrated computer capabilities.

Switch — A device which allows multiple computer devices to share the same Internet or LAN connection.

Tracert — A utility for tracing the path taken by packets across the Internet and latency assessing analysis along the route.

Waterfall — A graphical display of digital information.

WiFi — A form of network connectivity without a physical wired connection, although with limited range. Also known by its controlling standard, IEEE 802.11.

Wireless bridge — Low powered transmitter-receiver devices for providing point-to-point digital communications, usually Ethernet, such as for interfacing Internet services to areas without traditional means.

WOL — Wake-on-LAN functionality enables a user to remotely turn on a computer.

29.5 References and Bibliography

APPENDIX

See this book's accompanying CD-ROM for a listing of vendors and other resources for remote station construction.

REFERENCES

[1]Sepmeier, RBR.com, **www.rbr.com/.radio/ENGINEERING/95/13603.html**

[2]Remoterig by SM2O, **www.remoterig.com**.

[3]S. Ford, WB8IMY, *Remote Operating for Amateur Radio*, ARRL, 2010.

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Contents

Digital Communications

In this supplement, Steve Ford, WB8IMY, discusses the techniques involved in assembling and configuring station components for operating on the various HF and VHF digital modes. Today's digital communication choices range from keyboard based modes like classic RTTY, packet radio and PSK31, to digital voice, local high speed multimedia networks and VHF/UHF networks linked by the Internet. Related information may be found in the **Modulation** and **Digital Modes** chapters. In previous editions, this material formed Chapter 31. Unless otherwise noted, references to other chapters refer to chapters in the print version of the *ARRL Handbook*.

Amateur digital communication has always been a niche activity, but it has grown substantially over the years. From the end of World War II until the early 1980s, *radioteletype*, better known as *RTTY*, was *the* Amateur Radio digital mode. If you had visited an amateur RTTY station prior to about 1977, you probably would have seen a mechanical teletype machine, complete with rolls of yellow paper. The teletype may have been connected to the transceiver through an interface known as a *TU*, or *terminal unit*. An oscilloscope would probably have graced the layout as well, used for proper tuning of the received signal.

When affordable microprocessor technology appeared in the late 1970s, terminal units evolved as well. Some included self-contained keyboards and video displays, making the mechanical teletype obsolete. As personal computers evolved, they became perfect companions for TUs. In this configuration, the PC functioned as a "dumb terminal," displaying the received data *from* the TU and sending data *to* the TU for transmission. TUs of this era offered ultra-sharp receive filters that allowed hams to copy weak signals in the midst of interference.

In the late 1980s, conventional terminal units began to yield to sophisticated microprocessor devices known as *multimode controllers*. As the name suggests, these compact units handle several different digital modes in one package, typically RTTY, packet, AMTOR and PACTOR. Like TUs, multimode controllers are stand-alone devices that communicate with a personal computer acting as a dumb terminal. All of the heavy lifting is being done by the controller and its self-contained software known as *firmware*.

In the early 1990s, sound cards appeared for personal computers. As sound cards became more powerful, hams began to realize their potential. With the right software, a sound card could take received audio directly from the radio and translate it into digital information. The same sound card could also create various forms of digital audio modulation for transmission. The first "sound card mode" was PSK31, developed by Peter Martinez, G3PLX. In the years that followed, sound cards became more powerful and versatile. Hams responded by developing more new digital modes to take advantage of the advances.

Hardware controllers are still with us, but they are primarily used for modes like packet and PACTOR that require more processing muscle and precision timing than a typical personal computer can provide on its own. Other amateur digital modes such as D-STAR depend on specially designed transceivers that combine the radio hardware with dedicated digital processing firmware.

1 Sound Card Modes

Sound card technology dominates the amateur HF digital communications world. Although the term sound *card* is commonly used, the techniques discussed in this section apply to motherboard-embedded sound chip sets, which are extremely common in computer systems today, and to external sound processing devices. We'll use the term "sound card" to refer to any of these hardware implementations. See **Fig 1**.

The sound card modes in use today include PSK, RTTY, MFSK16, Olivia, Hellschreiber and MT63. There are also sound-card applications for digital voice, discussed later in this chapter and for slow-scan TV, discussed in the **Image Communications** supplement.

The 31-baud version of PSK, known as PSK31, is by far the most popular mode for casual HF digital communication. The popularity of PSK31 notwithstanding, radioteletype (RTTY) still remains the chief HF mode for contesting and DXing. All other HF digital modes play minor

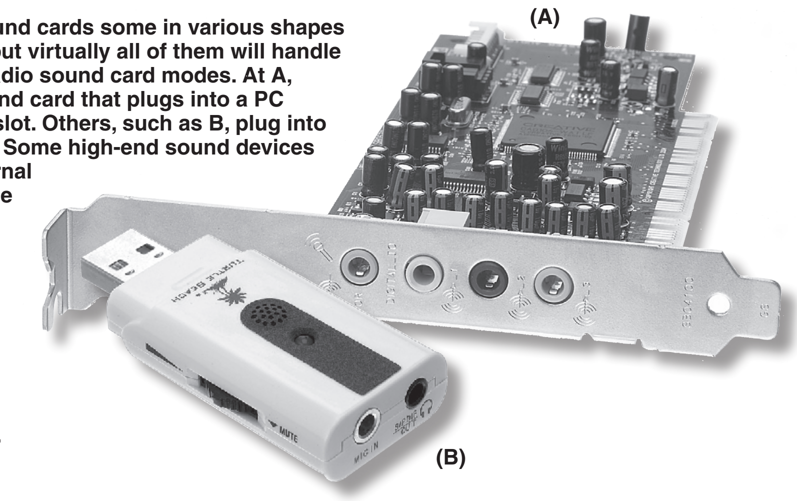

Fig 1 — Sound cards some in various shapes and sizes, but virtually all of them will handle Amateur Radio sound card modes. At A, a basic sound card that plugs into a PC expansion slot. Others, such as B, plug into a USB port. Some high-end sound devices use an internal card with the processing circuitry and an external breakout box with multiple input and output connectors.

roles, but each has characteristics that provide benefits depending on the use case. Olivia, MFSK16 and MT63, for example, provide more robust copy under poor conditions.

On VHF and above, the *WSJT* software suite is the sound card mode of choice for meteor scatter and moonbounce work. *WSJT* has also found experimental application on the HF bands. See the sidebar, "The WSJT Revolution."

Regardless of the mode in question, the sound card functions as the critical link. It is put to work as a digital-to-analog (D/A) and analog-to-digital (A/D) converter. In its A/D role, the sound card takes receiver audio and converts it to digital information. During transmission, the sound card is used as a D/A converter, taking digital information from the software application and creating a corresponding analog signal that is fed to the transceiver. (For more information on A/D and D/A converters, see the **Analog Basics** chapter.)

1.1 Which Sound Card is Best?

This is one of the most popular questions among HF digital operators. After all, the sound device is second only to the radio as the most critical link in the performance chain. Sound cards have traditional analog audio amplifiers, mixers and filters, all of which can introduce noise, distortion and crosstalk. A poor sound device will bury weak signals in noise of its own making and will potentially distort your transmit audio as well.

If you have a modest station and intend to enjoy casual chats and a bit of DXing, save your money. An inexpensive sound card, or the sound chipset that is probably on your computer's motherboard, is adequate for the task. There is little point in investing in a luxury sound card if you lack the radio or antennas to hear weak signals to begin with, or if they cannot hear you.

On the other hand, if you own the station hardware necessary to be competitive in digital DX hunting or contesting, a good sound card can give you a substantial edge. Other applications that require a lot of processing power, such as software-defined radio (SDR), require a high-performance sound card. Often vendors will offer a list of sound devices known to perform well with their equipment.

Sound cards convert analog audio signals to a set of digital samples, but this conversion from analog to digital isn't perfect, for several reasons. Here are some parameters to consider.

Sample Size

When a sound card takes a sample of the input voltage, it expresses it as a binary number with a certain number of bits. This is the *sample resolution,* or *sample size*. The sample resolution determines the number of steps between the smallest and the largest signal the card can measure. The greater the number of steps and the smaller they are, the more precise the samples will be. Larger steps introduce more *quantization noise*, so a sound card's signal-to-noise ratio is limited by the number of bits of resolution in each sample. For example, a card taking 8-bit samples measures only 256 voltage steps and cannot yield a signal-to-noise ratio better than about 49 dB. With 16-bit samples, there are 65,536 steps, and the ideal S/N rises to 98 dB.

Sample Rate

The clock that drives the A/D converter runs at a steady rate, known as the *sample rate*. As you might expect, a higher sample rate is required to accurately capture higher-frequency sounds. A waveform can be ac-

The *WSJT* Revolution

Hams routinely use meteors and the moon as radio reflectors for *meteor scatter* and *moonbounce* communication. You can read more about these activities in the chapter on **Propagation of RF Signals** and in the **Space Communications** supplement on the *Handbook* CD. For many years, meteor scatter and moonbounce required large antennas and high power RF amplifiers. CW was the mode of choice since a concentrated, narrow-bandwidth signal had the best chance to survive the journey and still be intelligible at the receiving station. That changed in 2001 when Joe Taylor, K1JT, unveiled a suite of sound card applications known simply as *WSJT*.

By using the sound card and computer as powerful digital signal processors, *WSJT* greatly reduced the station hardware requirements, making it possible for amateurs with modest stations to make meteor scatter and moonbounce contacts. Hams have also experimented with using some *WSJT* modes on the HF bands to make contacts using extremely low power. *WSJT* does not support conversational contacts with lengthy exchanges of information. Instead, the software allows for basic information exchange sufficient to meet the requirements that a contact has taken place.

WSJT is available for both *Windows* and *Linux*. It is a software suite that supports five different operating modes: *FSK441* for meteor scatter; *JT65* for moonbounce, but also being used occasionally on HF; *JT6M*, optimized for meteor scatter on 6 m; *EME Echo* for measuring the echoes of your own signal from the moon; and *CW* for moonbounce communication using 15 WPM Morse code.

The software is available for free downloading from **physics.princeton.edu/pulsar/K1JT**.

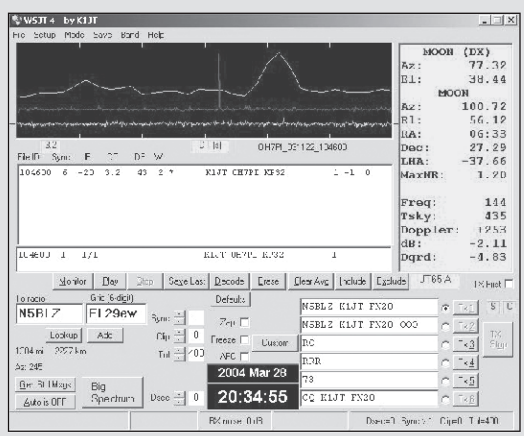

Fig A1 — WSJT software operating in the JT-65 mode.

curately captured by sampling at twice the highest frequency of interest. Energy at higher frequencies produces *aliases*, so sound cards put a low-pass filter ahead of the A/D converter, running at a cutoff frequency equal to one-half the sample rate. These filters cannot be perfect, so there's bound to be either some high frequency roll-off, or some distortion due to aliases sneaking through.

Linearity

If the sample steps aren't all exactly the same size, or the clock drifts up and down a little bit in frequency, distortion is introduced. The ideal sound card would have a perfectly linear A/D converter and a perfectly stable clock, but of course these are impossible to achieve. Good-quality sound cards do, however, have crystal-controlled oscillators as their clock source.

Sample Rate Accuracy

Even if the clock runs at a stable frequency, we won't get the desired result if it's running at the *wrong* frequency. Sample rate accuracy can be important for analog modes that aren't continuously synchronized. For these modes, one sound card is generating a signal and the other is receiving it, and the two cards are expected to be running at exactly the same sample rate. Distortion, or even loss of data, can occur if the rates are slightly different.

Remember that sound cards work by taking the analog audio signal at the input and converting it to digital information by sampling the audio signal at a very high rate, typically between 8000 and 11025 Hz for most ham applications. Sound cards can have sampling rate errors that will seriously affect weak-signal copy. For example, the laptop on which this chapter is being written has an actual sampling rate of 11098.79 Hz instead of the nominal 11025 Hz. This error not only affects the apparent frequency of an incoming tone, but can keep a program that requires a high degree of frequency stability, such as MFSK16, from maintaining consistent framing on incoming data. The result will be poor or inconsistent copy.

VoIP applications such as EchoLink and IRLP send a continuous stream of data from one sound card to another over the Internet. If the sender and receiver aren't running at the same rate, it can cause audio drop-outs, as the buffer at the receiving end becomes empty or overflows.

WSJT requires a high degree of accuracy but works around this problem by measuring the actual sample rate for sound card input and output (on some computers they are not the same) and then doing appropriate manipulations of the data. Most software doesn't have active sample error correction, however. If your software and hardware support it, you might realize better performance at a higher sample rate such as 12 kHz.

Sample rate accuracy is usually less of an issue for modes such as RTTY, PSK31, Olivia and DominoEX that synchronize the receiver with the sender frequently. In these modes, the sound card's clock is still used as the timing reference, but exact sound card timing is far less critical.

SOUND CARD STATION SETUP

Fig 2 shows a typical sound card station setup. A simplified sound card is shown here, but even the simplest of sound cards can be complicated. They can have as few as two external connections but there may be as many as twelve or more. You may find ports labeled LINE IN, MIC IN, LINE OUT, SPEAKER OUT, PCM OUT, PCM IN, JOYSTICK, FIREWIRE, S/PDIF, REAR CHANNELS or SURROUND jacks, just to name a few.

Depending on your computer, you may be able to choose your receive audio connection from either MIC INPUT or LINE INPUT. Anything else you find is not an analog audio input. If you do have a choice, use the LINE INPUT for the receive audio from your radio. Although the MIC INPUT jack can be used, it will have much more gain than you need and you may find adjustment quite critical. Some sound cards have an "advanced" option to select a 20 dB attenuator that will reduce gain and make the MIC INPUT jack easier to use.

If your only goal is to decode received signals, you need nothing more than an audio cable between the transceiver and the sound card. You should not need ground isolation for receive audio as it is at a high level and is normally not susceptible to ground loops. You may also be able to choose from several outputs that appear on the radio. Your radio may have SPEAKER, HEADPHONE, LINE OUT, RECORD, PHONE PATCH and DATA OUTPUT jacks available. These may be fixed output or variable output (using the radio's volume control). Be careful with radio's DATA OUTPUT jack — it may not work on all modes.

For the sound card transmit connection, you will have a choice of the computer's HEADPHONE OUTPUT, LINE OUTPUT, SPEAKER OUTPUT or a combination of these. The SPEAKER OUTPUT is usually the best choice as it will drive almost anything you hook to it. The SPEAKER OUTPUT has a low source impedance making it less susceptible to load current and RF. Any one of these outputs will usually work fine, provided you do not load down a line or headphone output by using very low impedance speakers or headphones to monitor computer-transmitted audio. The transmit audio connection must have full ground isolation through your interface, especially if it drives the MIC INPUT of the radio. This usually means adding an isolation transformer, as discussed in the next section.

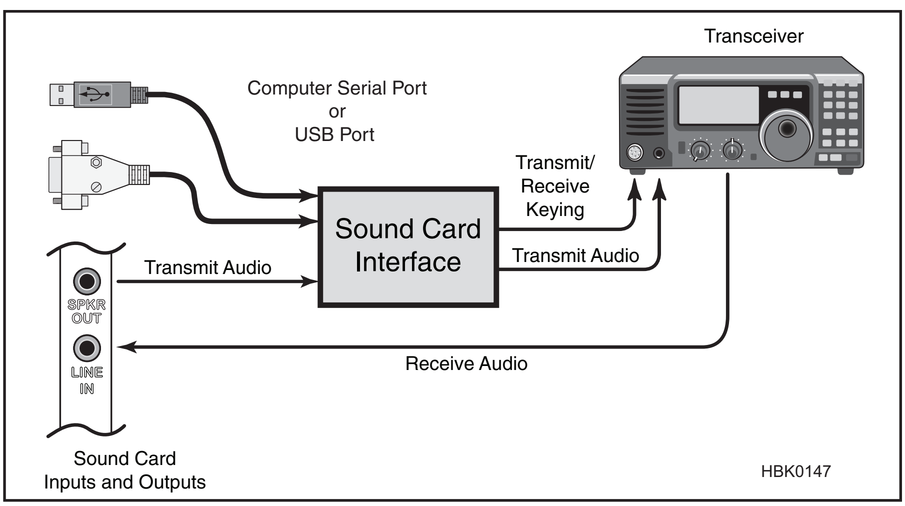

Fig 2 — A typical interface connection between a computer and a transceiver. Note that the transmit audio connects to the radio through the interface, and TR keying is provided by the computer serial port. Newer sound card interfaces are often designed to work with computer USB ports.

1.2 Sound Card Interfaces

In addition to providing audio connections between the sound card and your transceiver, you also need to provide a way for your computer to switch the radio between receive and transmit. This is where the *sound card interface* comes into play.

Commercial sound card interfaces such as the one shown in **Fig 3** match the audio levels, isolate the audio lines and provide transmit/receive switching, usually with your computer's serial (COM) or USB port. You can also make your own interface by simply isolating the audio lines and cobbling together a single-transistor switch to connect to your COM port. **Fig 4** shows some commonly used interface circuits.

In Fig 2 you'll notice that the transmit audio

Fig 3 — The MicroHam Digi Keyer is an example of a multifunction sound card interface. Some commercial devices include CW keyers, transceiver control interfaces and support for multiple transceivers.

connects to the radio through the interface. By doing so, the interface can provide isolation. Some interfaces also include a transmit audio adjustment, although this can also be accomplished at the computer, as described in the previous section.

It's important to mention that you may also be able to use the VOX function on your transceiver to automatically switch from receive to transmit when it senses the transmit audio from your sound card. This approach completely removes the need for a TR switching circuit, COM port and so on.

The weakness of this technique is that it will cause your radio to transmit when it senses *any* audio from your computer — including miscellaneous beeps, sounds or music. It's best to turn off these sounds from your computer so you don't transmit them accidentally. Another approach is to use a second sound card so that one can be used for regular computer audio applications and one dedicated to interfacing with the radio.

AFSK AND FSK

Most sound card modes rely on some form of frequency and/or phase-shift keying to create digitally modulated RF signals. This modulation takes place at audio frequencies with the sound card audio output applied directly to an SSB voice transceiver, either at the microphone jack or at a rear-panel accessory jack, and is called *audio frequency shift keying* (*AFSK*).

RTTY, PACTOR I and AMTOR signals can be sent using AFSK, and often are. It is also possible to transmit these modes by applying discrete binary data *directly* to the transceiver. This technique is known simply as direct *frequency-shift keying (FSK)*.

For example, each character in the Baudot RTTY code is composed of five bits. When modulated with AFSK, a "1" bit is usually represented by a 2125-Hz tone and is known as a *mark*. A "0" bit is represented by a 2295-Hz tone called a *space*. The difference between the mark and space is 170 Hz, called the *shift*. When applied to a single-sideband transceiver, this AFSK audio signal effectively generates an RF output signal that shifts back and forth between the mark and space frequencies.

A transceiver that supports FSK, however, can accept mark/space digital data directly from the computer and will use that information to automatically generate the frequency-shifting RF output. No audio signal is applied to the transceiver when operating FSK.

Is there an advantage to using AFSK or FSK? In years past, transceivers that did not support FSK operation often did not allow the use of narrow IF filtering. Those filters were reserved for CW, not the SSB voice mode used with AFSK. If you wanted to use RTTY with such a rig, you had to use AFSK and contend with the wider (2.4 kHz or so) SSB IF bandwidth, or else add an external audio filter. FSK-capable transceivers, on the other hand, allowed the RTTY operator to select narrow CW filters, reducing receive interference in crowded bands.

Many of today's transceivers offer adjustable-bandwidth digital signal processing (DSP) filters in the IF stages that can be used with any operating mode. This has effectively eliminated the FSK advantage, at least for receiving.

The appeal of FSK remains, however, when it comes to transmitting. A *properly modulated* AFSK signal is indistinguishable from FSK, but it is relatively easy to overdrive an SSB transmitter when applying an audio signal from a sound card (more on this in the next section). With FSK this is never an issue. You simply feed data from the computer to the radio; the radio does the rest.

This is why a number of RTTY operators still use FSK, and it's why transceiver manufacturers still offer FSK modes (sometimes labeled DATA or RTTY) in their products. Several sound card interfaces support FSK by providing a dedicated TTL circuit between the computer COM port, where the FSK data appears, and the transceiver FSK input. When used in this fashion, the sound card does not generate a transmit audio signal at its output. Instead, the RTTY software keys the various lines at the COM port to send the FSK data.

If the sound card interface you've chosen doesn't support FSK, you can build your own TTL interface using the circuit shown in Fig 4. This simple circuit uses a transistor that is keyed on and off by data pulses appearing on the COM port TxD pin (pin 3 on a 9-pin COM port).

It is important to note that FSK transceiver inputs can only be used for modes that are based on binary FSK, typically with 170 or 200-Hz shifts. These modes include RTTY,

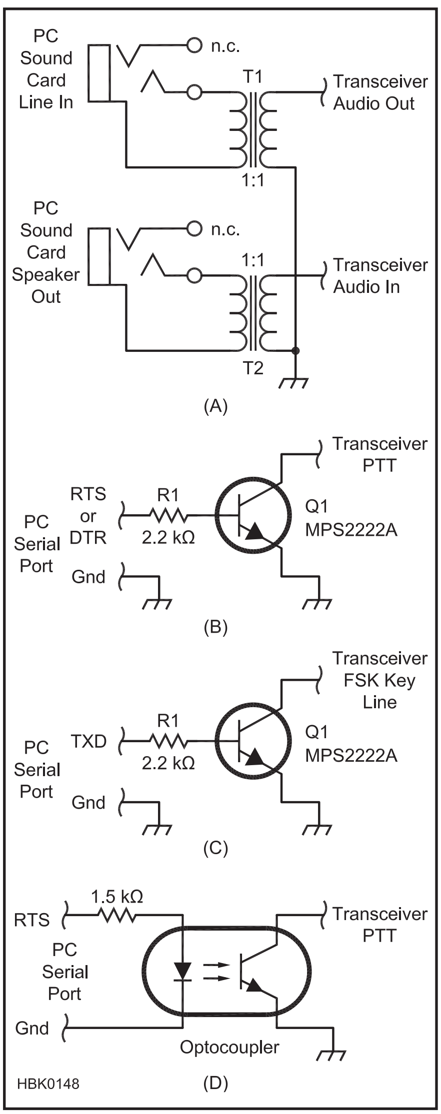

Fig 4 — Some commonly used interface circuits. At A, isolating the sound card and transceiver audio lines. T1 and T2 are 1:1 audio isolation transformers such as the RadioShack 273-1374. At B, a simple circuit to use the computer COM port to key your transceiver PTT, and at C, a similar circuit for FSK keying. Q1 is a general purpose NPN transistor (MPS2222A, 2N3904 or equiv). At D, an optocoupler can be used to provide more isolation between radio and computer. On a DB9 serial port connector: RTS, pin 7; DTR, pin 4; TxD, pin 3; GND, pin 5.

PACTOR I and AMTOR. You cannot use the FSK input to transmit multi-frequency or phase-shift modulated signals such as MFSK16 or PSK

Computer Power

You don't need an extremely powerful computer to enjoy digital operating. You can pick up an old 850 MHz Pentium laptop on eBay (**www.ebay.com**) for less than $300. You can probably find a similar desktop system for that price and even less. Either computer will be adequate for 90% of the software you are likely to use. Serious processing power only comes into play with software-defined radios or digital voice and image applications. For those endeavors, a 2 GHz system is best for smooth performance.

Every computer needs an operating system and that's where you may encounter some sticky issues. Until 2007, the most widely used operating system was *Windows XP*. Most Amateur Radio software available today was originally written for *XP*. Much of it will also run under *Windows Vista*, *XP's* replacement, but there are no guarantees. If you are upgrading to *Vista*, or if you've purchased a computer with *Vista* already installed, you'll need to test your ham applications for compatibility. One problem that crops up frequently involves the "Help" files that so many *Windows* programs use. *Vista* does not recognize the "old" *Windows* Help format, so when you click on Help (or a portion of the *Windows* application that uses the older Help format, such as the user manual), *Vista* may present you with an error message instead. No doubt ham programmers are already adapting to this change and re-writing their applications accordingly, but it may take some time for these revisions to make it into the marketplace.

Vista also requires more CPU power to run properly. Beware of buying an underpowered new or used computer with *Windows Vista* pre-installed (and beware of installing *Vista* on an anemic machine). To obtain decent performance from *Vista*, you need a minimum 2 GHz microprocessor and 1 GB of RAM.

The good news for *Windows* users is that *XP* is likely to be around for several years to come, although Microsoft will eventually stop supporting it. *Vista* is being replaced by *Windows 7*, which offers superior performance.

Of course, you don't have to use *Windows* to enjoy HF digital. The *Linux* operating system has been gaining in popularity and you can pick up *Linux* "distributions" on the Web free of charge. For a good example, check out *Ubuntu Linux* at **www.ubuntu.com**. Mac users will find *Mac OS* applications for digital modes such as APRS and many others. See Table 1.

1.3 Transmit Audio Levels

When applying sound card audio to a transceiver, it is critical to maintain proper levels. By overdriving the transceiver's audio input you may create a wide, distorted RF signal that will be difficult, if not impossible, to decode at the receiving end. Such an overmodulated signal will also cause considerable interference on adjacent frequencies.

As you increase the transmit audio output from your sound card, pay careful attention to the ALC indicator on your transceiver. The ALC is the automatic level control that governs the audio drive level. When you see your ALC display indicating that audio limiting is taking place, or if the display indicates that you are exceeding the ALC "range," you are feeding too much audio to the transceiver.

Monitoring the ALC by itself is not always effective. Many radios can be driven to full output without budging the ALC meter out of its "nominal" range. Some radios become decidedly nonlinear when asked to provide SSB output beyond a certain level (sometimes this nonlinearity can begin at the 50% output level). We can ignore the linearity issue to a certain extent with an SSB voice signal, but not with digital modes because the immediate result, once again, is splatter.

The simplest method to tell if your signal is clean is to ask someone to give you an evaluation on the air. For example, PSK31 programs commonly use a waterfall audio that can easily detect "dirty" signals. The splatter appears as rows of lines extending to the right and left of your primary signal, as shown in **Fig 5**. (Overdriven PSK31 signals may also have a harsh, clicking sound.)

If you are told that you are splattering, ask the other station to observe your signal as you slowly decrease the audio level from the sound card or processor. When you reach the point where the splatter disappears, you're all set.

If PSK31 is your primary digital mode, an alternative solution for *Windows* users is the PSKMeter by Software Science. This clever device samples the RF from your transceiver and *automatically* adjusts the audio output of your sound card until your signal is clean. The RF sampling port of the PSKMeter connects to your antenna coax with a T connector. The data is fed to your computer through an available COM (serial) port, or a USB port if you have a USB-to-serial converter. The PSKMeter software then analyzes the sampled signal and adjusts the master output volume of your sound card accordingly. The PSKMeter is available in kit form and can be ordered on the Web at **www.ssiserver.com/info/pskmeter**.

Whether you choose automatic or manual adjustments, don't worry if you discover that you can only generate a clean signal at, say, 50 W output. With PSK31 and most other sound card modes, the performance differential between 50 W and 100 W is inconsequential.

CONSISTENT AUDIO LEVELS

One of the perennial problems with sound devices is the fact that optimum audio levels have a tendency to differ depending on the software you are using. The mixer levels you set correctly for one application may be wildly wrong for another. And what happens when another family member stops by the computer to listen to music or play a game? They're likely to change the audio levels to whatever suits them. When it comes time to use the computer again for HF digital operating, you may get an unpleasant surprise.

The commonsense answer is to simply check and reset the audio levels before you operate. There are some software applications that will "remember" your audio settings and reapply them for you. One example is *QuickMix* for *Windows*, which is available free on the Web at **www.ptpart.co.uk/quickmix**. *QuickMix* takes a "snapshot" of your sound card settings and saves them to a file that you name according to the application (for example, "PSK31"), which can be reloaded next time you operate using that mode.

An even more elegant solution is the free *Sound Card Manager* for *Windows* by Roger Macdonald, K7QV, which you can download at **www.romacsoftware.com/Sound-Management.htm**. Whenever you start an

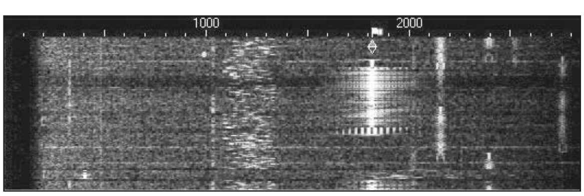

Fig 5 — The waterfall spectrum display built into popular sound card software can help detect overdriven PSK31 signals. Note the lines extending from the signal on the right, near the 2000 Hz marker, indicating splatter. The other signals are from properly adjusted transmitters.

Table 1
Sound Card Software

Windows

ALE
PCALE — **www.hflink.com**

Multimode
MixW — **www.mixw.net**
HamScope — **www.qsl.net/hamscope**
MultiPSK — **f6cte.free.fr/index_anglais.htm**
Ham Radio Deluxe — **www.ham-radio-deluxe.com**

Hellschreiber
IZ8BLY — **xoomer.virgilio.it/aporcino/Hell/index.htm**

MFSK16
IZ8BLY — **xoomer.virgilio.it/aporcino/Stream/index.htm**

PSK31
DigiPan — **www.digipan.net**
WinWarbler — **www.dxlabsuite.com/winwarbler**
W1SQLPSK — **www.faria.net/w1sql**
WinPSK — **www.moetronix.com/ae4jy/winpsk.htm**

Digital Voice
WinDRM — **www.n1su.com/windrm**

MacOS

Multimode
MultiMode — **www.blackcatsystems.com/software/multimode.html**
cocoaModem — **homepage.mac.com/chen**

Linux

Multimode
Fldigi — **www.w1hkj.com/Fldigi.html**

WINMOR
www.winlink.org/WINMOR

application (such as a piece of HF digital software), *Sound Card Manager* automatically reconfigures your sound card and then returns it to the default setting when you are done.

1.4 Sound Card Software

As you can see in **Table 1**, there is great deal of software available for sound-card-based digital modes. Some of the software applications are free, while others require registration and a fee.

There are applications dedicated to particular modes, such as *DigiPan* (PSK31) and *MMTTY* (RTTY). The trend in recent years has been to multimode programs that support many different digital modes in a single application.

Another trend has been toward *panoramic reception* where the software processes and displays all signals detected within the bandwidth of the received audio signal. The signal "signatures" are often shown within continuously scrolling *waterfall* displays like the one shown in **Fig 6**.

Panoramic reception is particularly popular among PSK31 operators because the narrow signals tend to cluster within a relatively small

Digital Communications and Public Service

In recent years, amateur digital communication has found frequent application in the realm of public service. There has been a proliferation of local and regional public-service networks, primarily using VHF packet as well as D-STAR, but three systems currently carry the lion's share of the long-haul traffic load.

Winlink 2000

Winlink 2000 is an Amateur Radio digital network with HF and VHF components. Both provide the ability to transfer e-mail to and from the Internet.

Winlink 2000 functions as a full-featured Internet-to-HF/VHF "star network" gateway system. The HF portion of the network is composed of Radio Message Server HF — *RMS HF* — stations. These stations are accessed through the use of PACTOR I, II or III and WINMOR using the multimode controller-based stations described in this chapter. On the VHF side, support is provided through *RMS Packet* stations. These packet radio stations can be accessed using common packet TNCs connected to FM voice transceivers.

Most VHF RMS Packet stations are on the air continuously. On the HF side, RMS HF stations throughout the world scan a variety of HF digital frequencies on a regular basis, listening on each frequency for about two seconds. By scanning through frequencies on several bands, these RMS HF stations can be accessed on whichever band is available at any given time.

All RMS Packet and HF stations link to a central group of redundant Common Message Servers. Since all e-mail messages coming to and from the Internet are stored on these servers and available to all RMS Packet and HF stations, Winlink 2000 users never have to designate a "home" BBS, as in the traditional packet radio world. You can send an e-mail from VHF to the Internet via a RMS Packet station in California and pick up the reply from an RMS HF station in South Africa.

In addition to text e-mail, Winlink 2000 is capable of handling file attachments such as images. However, the larger the attachment the longer it will take to send via radio. This is particularly true on VHF where most packet stations are still operating at only 1200 baud. See the Winlink 2000 Web site at **www.winlink.org**.

National Traffic System-Digital

The National Traffic System-Digital (NTSD) is based on the original Winlink structure now referred to as *Winlink Classic*. Unlike Winlink2000, which uses Internet linking between its Common Message Servers, NTSD is entirely RF based.

Most HF NTSD Mailbox Operations (MBOs) are accessed using PACTOR I or II. Designated NTSD operators in each region and local area relay messages, either between regions or to and from the local area stations. The hierarchical NTSD structure is discussed at **home.earthlink.net/~bscottmd/n_t_s_d.htm**.

Traditional packet radio is often used at the local level. In fact, NTS packet messages can be initiated and sent by any packet-capable operator. Messages for delivery are posted on cooperating NTS PBBSs (Packet Bulletin Board Systems). Messages come into these BBSs from the NTSD HF network, or from local packet networks in nearby sections or regions. In addition, any NTS voice messages that might not have been picked up on a voice net can be transcribed to text and posted to an NTS PBBS.

Global ALE High Frequency Network

Global ALE High Frequency Network (HFN) is an international Amateur Radio Service organization of ham operators dedicated to emergency/relief radio communications. The main purpose of the network is to provide efficient communications to remote areas of the world using amateur Automatic Link Establishment (ALE) as described in this chapter. The network supports direct station-to-station emergency text messaging as well as the ability to port text messages to and from the Internet. See **hflink.com/emcomm/.**

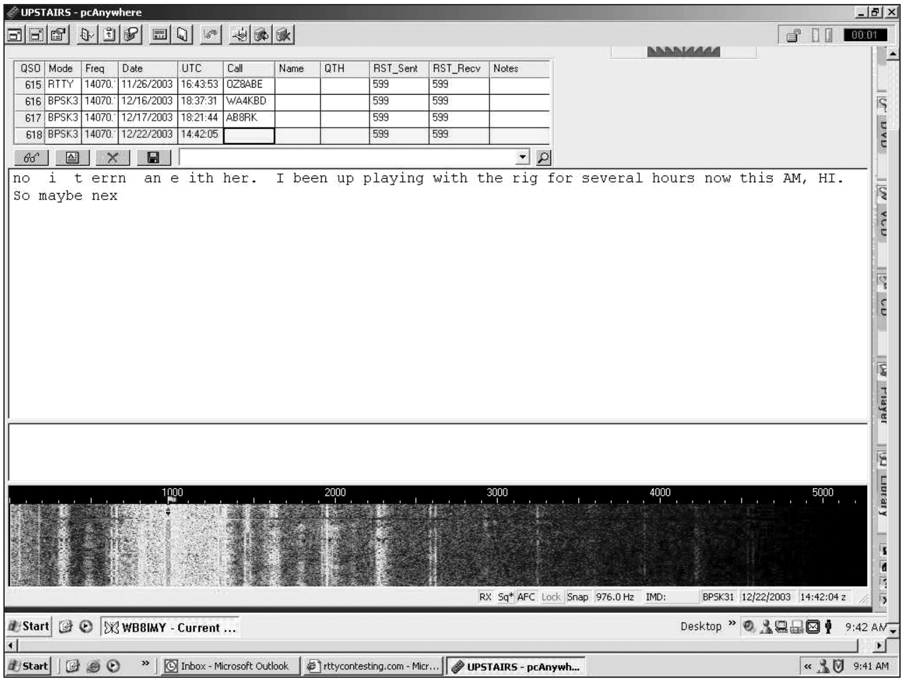

Fig 6 —Multimode sound-card applications typically support a variety of modes such as RTTY, PSK31, Olivia and MFSK16. Sent and received text appear in the white box. At the bottom of the screen is a waterfall tuning display. Tune the transceiver VFO to the calling frequency and then select stations to work by clicking on the signal trace in the display.

range of frequencies. By using panoramic reception, an operator can simply click the mouse cursor on one signal trace in the waterfall after another, decoding each one in turn.

The weakness of panoramic reception appears when wide IF filtering is used to display as many signals as possible. The automatic gain control (AGC) circuit in the receiver is acting on everything within that bandwidth, working hard to raise or lower the overall gain according to the overall signal strength. That's fine if all the signals are approximately the same strength, but if a very strong signal appears within the bandwidth, the AGC will *reduce* the gain to compensate. The result will be that many of the signals in the waterfall display will suddenly vanish, or become very weak, as the AGC drops the receiver gain. In cases where an extremely strong signal appears, *all* signals except the rock crusher may disappear completely.

The alternative is to use narrower IF or audio filter settings. These will greatly reduce the waterfall display width, but they will also remove or reduce strong nearby signals.

2 Packet Radio

Although the heyday of traditional packet radio has passed, it still survives in the form of networks devoted to specific applications such as emergency communication (see the sidebar "Digital Communications and Public Service") and DX spotting. A variant of packet radio also finds popular use in the Automatic Packet/Position Reporting System (APRS), addressed in a later section.

2.1 The Packet TNC

In the beginning, there was *X.25*, a protocol for wide-area digital networks that typically communicated over telephone lines. X.25 works by chopping data into strictly defined *packets* or *frames* of information. Each packet is sent to the destination device where it is checked for errors. If errors are discovered, the packet must be sent again to ensure that received data is 100% error free.

In the early 1980s, amateurs began adapting X.25 for over-the-air digital communications. The result was *AX.25*. The new AX.25 protocol worked in much the same way, although it identified each message by sender and destination station call signs and added a Secondary Station ID (SSID) in a range from 0 through 15.

To create and decode these AX.25 packets, hams invented the *terminal node controller*, or *TNC*. TNCs do much more than assemble and disassemble data; they are miniature computers unto themselves. A TNC is also programmed to work within a radio network where there may be other competing signals. For example, to maximize the throughput for everyone on the same frequency, a TNC is designed to detect the presence of other data signals. If it has a packet to send, but detects a signal on the frequency, it will wait until the frequency is clear. TNCs also have a variety of user adjustments and other features, such as a mailbox function to store messages when the operator is away.

Regardless of the changes in packet radio, the TNC is still a vital component. In essence, a TNC functions as a "radio modem." It acts the middleman between your radio and your computer. The TNC takes data from your computer, creates AX.25 packets and then transforms the AX.25 formatted data into audio signals for transmission by the radio. Working in reverse, the TNC demodulates the received audio, changes it back into data, disassembles the AX.25 packets and sends the result to the computer.

For 300 and 1200-baud applications, TNCs create signals for transmission using AFSK. The most common is 1200 baud packet, used primarily at VHF. When creating a 1200-baud signal, a *mark* or 1 bit is represented by a frequency of 1200 Hz. A *space* or 0 bit is represented by a frequency of 2200 Hz. The transition between each successive mark or space waveform happens at a rate of 1200 baud. The frequencies of 1200 and 2200 Hz fit within the standard narrowband FM audio passband used for voice, so that AFSK is accomplished by simply generating 1200 and 2200 Hz tones and feeding them into the microphone input of a standard FM voice transmitter.

FSK, not AFSK, is used for 9600 baud packet. The data signal is filtered and encoded and then applied directly to the FM transmitter, after the microphone amplifier stage, through a dedicated port.

A block diagram of a typical TNC is shown in **Fig 7**. You'll note that it has a serial interface connecting to a "terminal." Most commonly, the terminal is a full-fledged computer running terminal software. Data flows to the computer and vice versa via this interface. At the heart of the TNC is the microprocessor and the attendant *High-level Data Link Controller*, or *HDLC*. The microprocessor is the brain of the unit, but the HDLC is responsible for assembling and disassembling the packets. The modem is simply that — a modulator (changing data to audio tones) and demodulator (changing audio tones back to data).

You can still find TNCs for sale from several manufacturers. There are also several transceivers with packet TNCs built in.

Another solution is a software TNC known

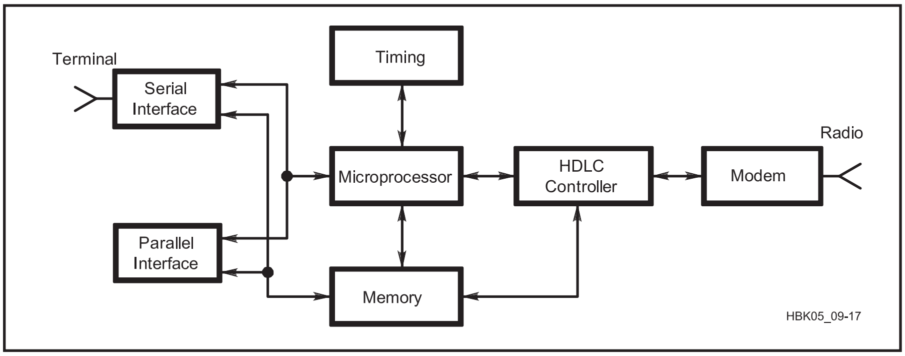

Fig 7 — A block diagram of a typical packet radio TNC.

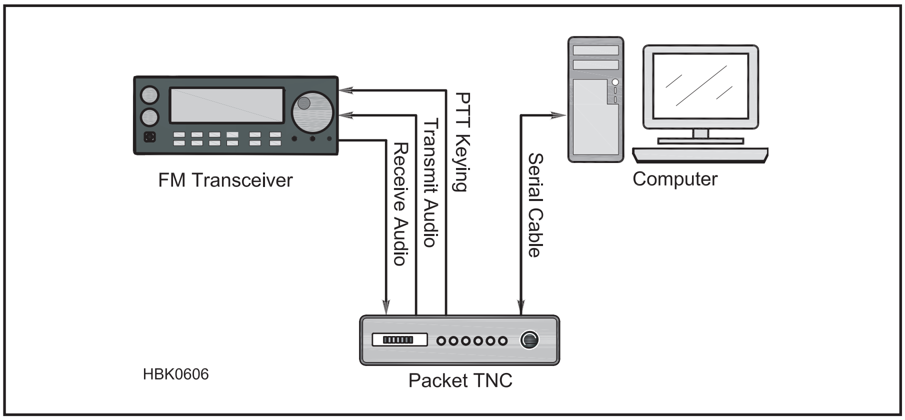

Fig 8 — A diagram of a packet radio station built around a hardware TNC.

as the *AGW Packet Engine*, or *AGWPE*, developed by George Rossopoylos, SV2AGW. The software is downloadable at **www.sv2agw.com/downloads**. With *AGWPE* and a sound card interface as described in this chapter, it is possible to operate packet radio without a hardware TNC — assuming that your primary packet software application includes the ability to interface with *AGWPE*.

2.2 Talking to a TNC

All hardware TNCs are functionally the same. When you buy a stand-alone TNC it usually includes a cable for connecting it to the radio, but you'll have to attach the appropriate mic and speaker jack connectors for your radio. You'll also have to furnish the cable that connects the TNC to your computer at the COM port. In most cases this is an RS-232 serial cable. See **Fig 8** for a typical setup. Most ham TNCs have yet to migrate to USB at the time of this writing. TNCs integrated into radios may need a cable between the radio's TNC port and a computer.

TNC manufacturers often supply the software necessary to communicate with the TNC, but any terminal program will work. You'll need to start the software and specify the COM port you'll be using, and set the baud and data parameters for that port. Refer to the manual for the specific program you've chosen. The baud rate of your computer must match the baud rate of your TNC. Some TNCs will automatically set their baud rate to match the computer; other TNCs have software commands or switches that determine the baud rate. Again, you'll need to refer to your manual for specific instructions. When setting the data parameters, 8-N-1 is normally used: 8 data bits, no parity, and 1 stop bit.

When you switch on the TNC, you should see some sort of "greeting" text on your screen. That's the first sign that all is well. If you see a bunch of gibberish, it means that the parameters of the TNC and computer don't agree and you'll have to make adjustments.

2.3 TNCs and Radios

Tones for 1200 baud can be fed directly into the microphone input of any VHF FM voice transceiver with an appropriate cable. Packet at 9600 baud requires an FM transceiver with a dedicated 9600-baud packet input, as noted earlier.

If you opt to craft your own cable, check your transceiver manual for the wiring diagram of the microphone jack. In most cases, there are separate connections for the audio input and the push-to-talk (PTT) line. (The TNC grounds the PTT line to key your transceiver.) Some transceivers also make receive audio available at the microphone jack for use with speaker/microphone combos. You can use this line to feed audio to the TNC. If it isn't available, you will have to make a separate connection to the transceiver's external speaker jack.

When you are setting up your TNC, be careful about the transmit audio level. Too high a level will create distorted signals that won't be decodable at the receiving station.

An easy way to check your transmitted signal is to use the TNC *calibrate* function. Get to the command mode (CONTROL-C) and enter **cmd: CALIBRATE**. Listen to your transmitted signal with another rig and raise the audio level from the TNC until the received volume seems to stop increasing. Now reduce the audio from the TNC until you can just hear a volume decrease in the receiver. Reduce it a bit more and you're done. Exit the calibrate function.

Some TNCs have an audio output adjustment on the board, some have an adjustment accessible through a hole in the side of the unit, and some have two fixed output levels selectable with a jumper. If one of these does not work, you may have to open up the transceiver and find the mic gain control. If this is necessary, be sure you adjust the mic gain control and *not* the deviation control (which can change the bandwidth of your signal).

2.4 TNC Timing

The TNC's TXDELAY parameter specifies the delay interval between the time the TNC keys the radio and the time it starts sending data. Normally 300-400 ms are adequate, but some transceivers take longer to settle after the keying line is triggered. If you have a problem being heard and your audio seems normal, try increasing TXDELAY to 400-600 ms.

On a busy network, packets and packet acknowledgements fly back and forth at a furious rate. One way to keep interference to a minimum is to manipulate the RESP and DWAIT parameters in conjunction with PERSIST and SLOTTIME to allow staggered transmissions.

RESP is the time delay between reception of a packet and transmission of an acknowedgement. DWAIT sets the delay between the time when activity is last heard on the channel and the moment your radio transmits. You should set values of RESP and DWAIT to the values recommended in your area (check with the person managing the local network or PBBS). Your TNC probably accepts a value in "counts" rather than in milliseconds, so don't forget to convert by the proper value in order to arrive at the correct

timing value in milliseconds. For example, if you have been asked to set DWAIT to 600 ms and the units of DWAIT for your TNC are 10 ms per count, then you would command DWAIT = 60.

Most TNCs contain commands called PERSIST and SLOTTIME, which help enormously in avoiding interference. PERSIST sets the probability that a packet will be transmitted during a given time interval called a SLOTTIME. The parameter SLOTTIME governs the interval between transmission timing "slots." Initially, PERSIST should be set to approximately 64 and SLOTTIME to a value of about 10, which is equivalent to 100 ms.

FRACK (frame acknowledgement) should be set to 6 and RETRY to 10. FRACK sets the number of seconds between retries and RETRY sets the number of times your TNC will try to send a packet and gain acknowledgement of it before it gives up and disconnects

2.5 Monitoring

Start by listening to an active packet frequency in your area. With the radio cable connected, turn on your radio and increase the receiver volume partway. Some TNCs include an LED indicator that shows that the TNC is receiving audio. Turn up the squelch control on the radio until the LED is extinguished. Tune the rig to any odd numbered frequency between 144.91 and 145.09, or between 145.61 and 145.79 MHz, and set the rig for simplex operation. Your best bet may be to search for a DX PacketCluster, or try monitoring APRS activity on 144.39 MHz. When you hear the buzzing packet signals and see text on your screen, you'll know you've hit the jackpot.

Depending on the type of activity you are monitoring, you may see what appears to be nonsense. If you are monitoring APRS, you'll see strings of numbers. These are latitude/longitude position reports. On PacketClusters, you'll see DX call signs and frequencies.

2.6 "Connected" vs "Unconnected"

When discussing TNCs and networks, it is important to understand the difference between connected and unconnected communication.

If you are simply monitoring local packet transmissions, your TNC is in an *unconnected* state. What you see is what you get. If a signal is garbled by noise or interference, you'll see nothing on your screen (unless you've enabled the PASSALL function, in which case you'll see gibberish). If you transmit an unconnected packet, the signal simply leaves your antenna destined for nowhere in particular. Some stations may decode it, some may not.

When your TNC is operating in a *connected* state, everything changes. When you are connected, your station is linked to another station in a "virtual" sense. In a connected state, every packet you send is intended specifically for the receiving station (even though others can see it).

When your TNC transmits a packet, it starts a countdown clock. If the clock reaches zero before your TNC receives an acknowledgement (known as an *ACK*) that the packet arrived without errors, it will send the same packet again. When the packet is finally acknowledged, the TNC will send the next packet. And so it goes, one packet after another. The operator at the other station may also be sending packets to you since this communication process can flow in both directions simultaneously.

The big advantage of the connected state is that data is delivered error-free. One packet station can connect to another directly, or through a series of relaying stations. Error-free can be a disadvantage, too. Specifically, a connected state works best when signals are strong and interference is minimal. Remember that if too many packets are lost — by either not arriving at all or arriving with errors — the link will fail. That's why AX.25 packet radio tends not to work well on the HF bands. With all the noise, fading and interference, packets are often obliterated enroute.

Unconnected packets are ideal for applications where you are transmitting essentially the same information over and over. Since unconnected packets can be decoded by any station, they are an excellent means of disseminating noncritical data (data that doesn't need guaranteed error-free delivery) throughout a given area. If a station fails to decode one packet, it merely waits for the next one. APRS uses exactly this approach.

3 The Automatic Packet/Position Reporting System (APRS)

The Automatic Packet/Position Reporting System, better known as *APRS* (**aprs.org**), is the brainchild of Bob Bruninga, WB4APR. In fact, APRS is a trademark registered by WB4APR. The original concept behind APRS involved tracking moving objects, and that's still its primary use today. However, APRS has been evolving to become an amateur network for other applications such as short text messaging, either from ham to ham, or between hams and non-hams through APRS Internet gateways.

Mobile APRS stations communicate their positions based on data provided by onboard Global Positioning System (GPS) receivers. The GPS receivers are attached to either packet radio TNCs or simplified packet devices known as *position encoders*, which in turn are connected to transceivers (see **Fig 9**). At receiving stations, various APRS software packages decode the position information and display the results as icons on computer-generated maps such as the one shown in **Fig 10**. When a station moves and transmits a new

Fig 9 — A 2 meter FM handheld transceiver attached to an APRS position encoder.

Fig 10 — A snapshot of APRS activity using *UI-View* software. Note the icons representing various mobile and fixed stations.

position, the icon moves as well.

Virtually all APRS activity takes place today on 144.39 MHz using 1200-baud packet TNCs and ordinary FM voice transceivers. In areas where the APRS network is particularly active, you may hear traffic on 445.925 MHz as well. There is also some activity on HF.

3.1 Setting Up an APRS Station

If you own a 2 meter FM voice transceiver, you already have the primary component of your APRS station. Tune your radio to 144.39 MHz and listen for packet transmissions. If you hear them, it means you have APRS activity in your area.

To decode APRS packets, you'll need a TNC, and it doesn't necessarily have to be "APRS compatible." APRS compatibility is only a factor if you wish to connect the TNC to a GPS receiver to transmit position data.

If all you want to do is monitor APRS activity, you do *not* need a GPS receiver. If you want to participate in the local APRS network from a fixed (non-moving) station such as your home, you still do not need a GPS receiver. Just determine your home latitude/longitude coordinates and you can use them to establish the location of your home station on the network. There are numerous sites on the Internet that will convert your home address to a correct latitude and longitude.

The only APRS station that requires a GPS receiver is a *moving* station. The good news is that almost any GPS receiver will do the job. It does not have to be elaborate or expensive. The only requirement of an APRS-compatible GPS receiver is that it provide data output in *NMEA* (National Maritime Electronics Association) format. Note that many GPS receivers advertise the fact that they provide data output, but some do it in a proprietary format, not NMEA — check the manual. See **Fig 11** for a diagram of a typical APRS station with a GPS receiver.

APRS-compatible TNCs and tracking devices have standardized on the NMEA 0183 protocol. They expect data from the GPS receiver to be in that format so they can extract the necessary information and convert it into AX.25 packets for transmission. If the data from the GPS receiver is incompatible, the TNC or position encoder won't be able to make sense of it.

The final component of your APRS station is software. You'll need software to display the positions of APRS stations, along with other information contained in their transmissions. APRS software is also essential if you want to communicate over the APRS network from a fixed or portable station. Note, however, that APRS software is *not* necessary for mobile stations that wish to merely transmit APRS beacons for tracking purposes. That function is carried out automatically using the GPS receiver and APRS-compatible TNC or tracking device; it does not depend on software.

The most popular APRS *Windows* program is *UI-View*. *UI-View* was created by the late Roger Barker, G4IDE. You'll find it on the Web at **www.ui-view.org**. The 16-bit version is free for downloading. To use the 32-bit registered version, hams are asked to donate to their local cancer charities. Details are available on the *UI-View* Web site. For the Macintosh, there is *MacAPRS* available from **www.winaprs.com**. For *Linux* there is *Xastir,* available for download at **www.xastir.org**.

APRS software, regardless of the operating system, is designed to talk to the packet TNC, processing the incoming APRS data and creating icons on your computer screen. The application also uses the TNC to transmit APRS data. This means that the software and the TNC must communicate with each other at the same baud rate. Every APRS application has a setup menu to program the correct parameters for various TNCs.

Depending on the software, there may be other features such as logging or messaging. APRS software changes rapidly, so check the help file or manual for specific instructions.

3.2 Maps and APRS

No matter which APRS software you choose, one absolutely critical aspect is the mapping function itself. To get the most from APRS, your software maps must be as comprehensive as possible, preferably with the ability to show detail down to street level.

Downloadable APRS software applications generally do not come with detailed maps. Detailed map files are numerous and large, impractical to bundle with every APRS program. Instead, most applications are designed to import user-created custom maps, or to work with existing commercial mapping programs such as Microsoft *Streets*, Delorme *Street Atlas* and *Precision Mapping*.

UI-View, for example, has the ability to automatically load and display maps from *Precision Mapping*. You must purchase and install *Precision Mapping* on your PC, then download and install a small *Precision Mapping* "server" application into *UI-View*.

Each APRS transmission includes characters that define the type of map icon that will be displayed at the receiving end. If you are operating a fixed station, your APRS software will allow you to choose your icon. If you are a mobile station using a traditional TNC, you'll need to define your chosen icon in your beacon statement. APRS-compatible TNCs give you the ability to do this. APRS position encoders also allow you to choose your icon when you program the unit. Your mobile icon might be a car, boat or airplane.

3.3 APRS Position Encoders

You can create a mobile APRS station with a VHF FM transceiver, a TNC and a GPS receiver. Wire everything together, connect an

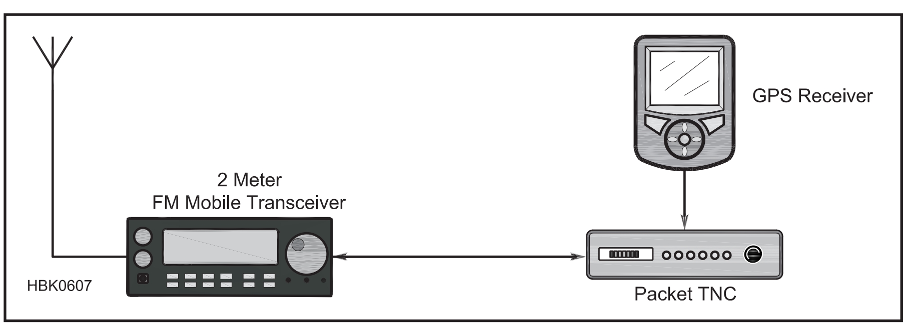

Fig 11 — Diagram of an APRS station. This configuration includes a GPS receiver, although the receiver is only required if the station is mobile. In mobile applications, a position encoder can be substituted for the packet TNC.

Fig 12 — Some APRS position encoders, such as this RPC Electronics RTrak, combine the GPS receiver, packet circuitry and 2 meter transmitter into a single device.

antenna and dc power and you're set. For hams on the go, however, it's common to replace the full-fledged TNC with an APRS *position encoder*, also referred to as an APRS *tracker*. A position encoder is a compact device designed for one purpose: to receive data from the GPS receiver, assemble APRS packets from the data and create modulated signals for use by the transmitter. Some position encoders include GPS receivers in their designs. You'll even find position encoders that are complete packages incorporating tiny GPS receivers and low power FM transmitters (**Fig 12**).

To use a position encoder you must program it the same way that you initially program a TNC. Like TNCs, position encoders connect to computer serial or USB ports for programming and most come with their own programming software. You must enter your call sign and other information such as your beacon interval (how often you want the position encoder to transmit your position). Most position encoders allow you to set the beacon interval to a certain amount of time (say, every two minutes). Some position encoders can be configured to transmit position beacons after a certain distance (every mile), or whenever the vehicle turns a corner.

3.4 APRS Networking Tips

One of the key features of APRS is that while it uses AX.25 to transport its messages, it essentially ignores all the AX.25 connection-oriented baggage. Unlike traditional packet radio, APRS stations do not establish "connections" with each other. Instead, APRS packets are sent to no one in particular, meaning to *everyone*.

Every APRS station has the ability to function as a digital repeater, or *digipeater*. So, if it receives a packet, it will retransmit the packet to others. As other digipeaters decode the same packet, they will also retransmit and spread it further. This is known as *flooding* and is illustrated in **Fig 13**.

As an APRS user, you can set up your station to address its packets through specific digipeaters according to their call signs. But when you're traveling, how do you determine which digipeaters you should use?

PATHS AND ALIASES

In the packet world, nodes and digipeaters can have *aliases*. A digipeater call sign may be W1AW-1, but it can also carry an alias, using the MYALIAS command in the digipeater TNC. Perhaps the digipeater alias would be NEWNG (meaning the ARRL HQ home town of Newington). You can route packets through the digipeater by addressing them to W1AW-1, or simply by addressing them to NEWNG. Any station that is set up to respond to an alias is capable of handling your packets automatically, even if you don't know its call sign.

Unlike typical packet use of aliases in which a given single station has a specific alias, APRS specifies standard digipeater aliases that nearly all stations use. This means that you can travel anywhere in the country and still participate in the APRS network without knowing digipeater call signs. (Otherwise, you'd have to reconfigure your TNC whenever you moved from one area to another.)

The most common APRS digipeater alias is *WIDEn-N*. The letters "n" and "N" represent numbers. The first (left-most) "n" designates how many WIDE digipeaters will relay your packets, assuming they can receive them. WIDE2, for instance, is the same as saying that you want your packets relayed through

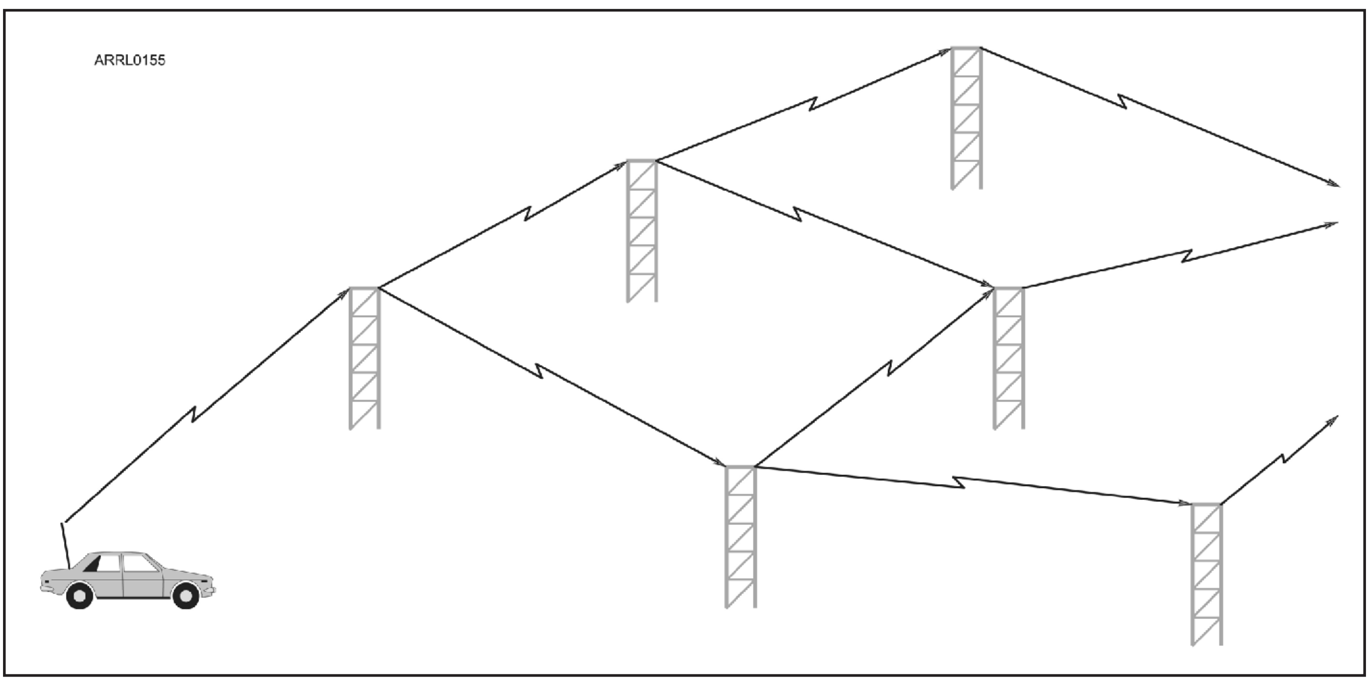

Fig 13 — In this example, an APRS packet is transmitted by a mobile station and is retransmitted by a nearby digipeater. Depending on how the mobile operator configured his TNC or tracker's path, the packet will be picked up and repeated by several other digipeaters. This is known as flooding.

two WIDE digipeaters. The second "N" is the *Secondary Station Identifier* (SSID). The SSID is used in APRS networks as a means of limiting how often (and how far) a packet can be repeated.

Here's how it works. Each time your packet traverses a WIDEn-N digipeater, the digipeater subtracts 1 from the SSID as it retransmits. The next digipeater deducts 1 and so on until the SSID reaches zero, at which time the packet will not be repeated again. This has the effect of limiting the flood radius. See **Fig 14**.

When you configure a TNC or position encoder for use with APRS, you can use these aliases to set up the paths for the beacon packets you'll be transmitting. In most devices this is accomplished with the UNPROTO parameter, sometimes simply referred to as the "Path." If you are a fixed station (a station at home, for instance), set your path as **WIDE2-2** (or with a traditional TNC UNPROTO statement, set it to APRS VIA WIDE2-2). This designates that your reports will be relayed by *two* WIDEn-N digipeaters and limits the spread beyond those repeaters to just two retransmissions. Set your TNC to beacon once every 30 minutes. That's sufficient for a fixed station.

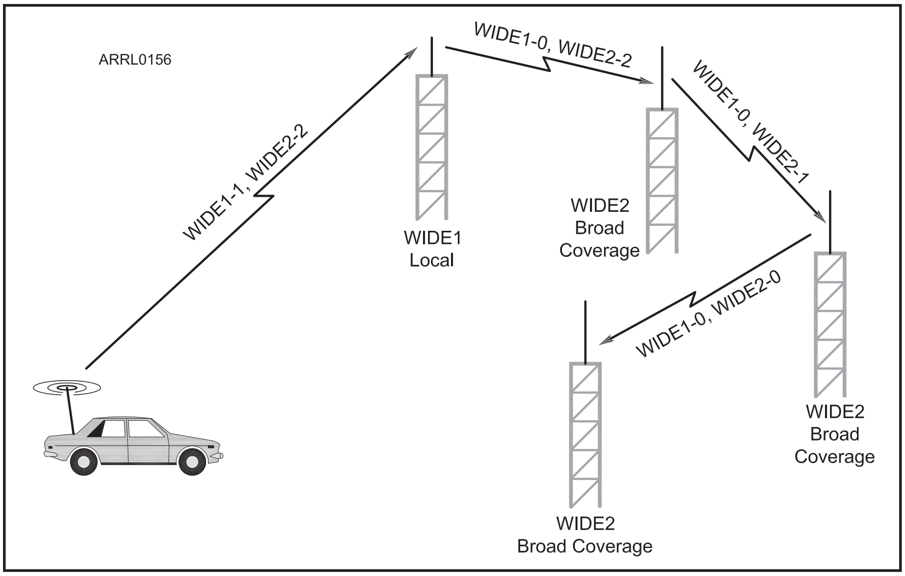

Fig 14 — By using the WIDEn-N system, we can limit packet flooding in a local network and greatly reduce congestion. The mobile station in this example has his path set as WIDE1-1,WIDE2-2. Notice how his packet propagates through the network and how the SSID number is reduced by one each time the packet is repeated through a digipeater with a corresponding alias. When it reaches the third WIDE2 digipeater, the counters all reach zero and digipeating stops.

If you are running APRS from a car, try **WIDE1-1,WIDE2-1** (or APRS VIA WIDE1-1,WIDE2-1). WIDE1-1 ensures that your packet will be picked up by at least one local digipeater or a home station acting as a fill-in digipeater and relayed at least once. WIDE2-1 gets your packet to another, presumably wider-coverage digipeater, but limits the retransmissions beyond this point. It's wasteful of the network to set up wide coverage for a station that is rapidly changing its position anyway. Mobile stations that are in motion should also limit their beacon rate to once every 60 seconds, or once per mile, whichever comes first.

Never invoke extremely wide coverage, such as a WIDE5-5 path, unless you are way out in the hinterlands and need every relaying station available to get your packets into the network.

Another popular alias is the "single state" — SSn-N — to limit the spread of your packets to a specific state or area within a state. To keep packets within the state of Connecticut, for example, you could use the SSn-N alias in a path statement, like this: CT1-1, CT2-2. This path assures that local Connecticut stations (CT1-1) will repeat the packets, and that broad-coverage stations (CT2-2) will relay them throughout a large portion of the state. APRS digipeaters outside Connecticut, however, will not respond to these packets because they won't recognize the CT2-2 alias (although they will recognize an alias for their state). The packets will still be heard across state borders but will not be digipeated or add to the packet activity in a neighboring state.

4 PACTOR

PACTOR is a type of HF digital communication that, unlike many other HF modes, offers error-free text and file transfers. PACTOR communication resembles packet radio in that it establishes a "link" between two stations. Data is sent in discrete frames and each frame is acknowledged by the receiving station. This rapid back-and-forth exchange creates PACTOR's distinctive *chirp-chirp-chirp* signal. Through robust coding and sophisticated modulation techniques, PACTOR is often able to maintain the link even in the face of significant noise, fading and interference.

PACTOR I, introduced in the early 1990s, has been largely superseded by PACTOR II,

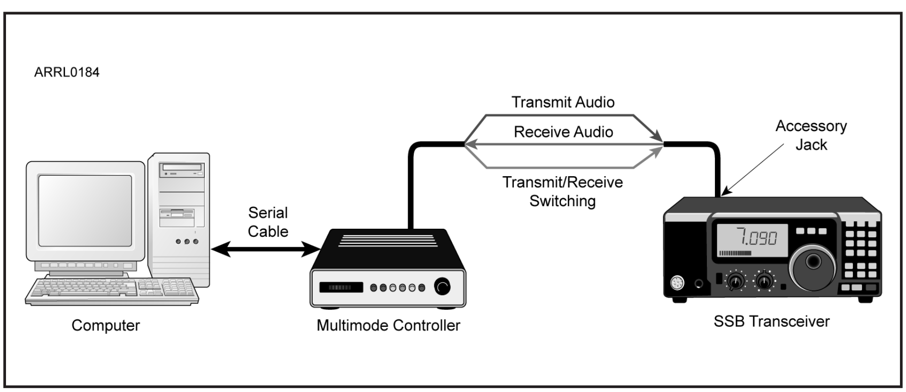

Fig 15 — A PACTOR station with a multimode controller. For PACTOR II and III operation, the controller must be a model manufactured by the SCS Corporation.

which provides faster throughput in difficult conditions. Both PACTOR I and II generate signals that occupy 500-Hz bandwidths. PACTOR III offers even more efficient communication, but its signal occupies a bandwidth in excess of 2000 Hz.

To set up a PACTOR station, you must purchase a stand-alone multimode controller that includes the PACTOR mode. As mentioned at the beginning of this chapter, multimode controllers are microprocessor-based devices that support several different digital modes in a single package. A typical multimode controller might include PACTOR, packet, RTTY and more. Controllers manufactured by Kantronics (**www.kantronics.com**) and Timewave (**www.timewave.com**) include PACTOR I. For PACTOR II or III, you must purchase a controller made by Special Communications Systems (**www.scs-ptc.com**), the original developers of PACTOR.

Fig 15 illustrates a typical PACTOR station built around a multimode controller. The computer is functioning only as a dumb terminal for the controller in this application, so it does not have to be particularly powerful. All that is required is basic terminal software as described in the section on packet TNCs. More sophisticated software applications can provide a smoother, easy-to-use interface, but these require more capable computers.

A PACTOR station requires an SSB transceiver capable of switching from transmit to receive within approximately 30 ms. Most modern HF transceivers can meet this requirement, but not all. *QST* magazine Product Reviews test this specification for all HF transceivers. The transmit audio supplied by the controller can be fed to the microphone or accessory jack to operate AFSK, which is the standard procedure, although PACTOR I can also operate using FSK.

The most popular use of PACTOR on amateur frequencies today is within the *Winlink 2000* network. PACTOR is also widely used as the HF digital arm of the National Traffic System-Digital (NTSD). See the sidebar "Digital Communications and Public Service."

5 High Speed Multimedia (HSMM)

Wireless networking using IEEE 802.11 standards has seen explosive growth during the last several years. Coffee shops, fast-food restaurants, hotels, airports and many other high-traffic locations now include wireless Internet (WiFi) hotspots. Some hotspots offer free Internet access while other charge an access fee, payable with your credit card.

Wireless networks are also popular at home. Establishing a home network is as simple as installing a *wireless router* to manage the data flow from the broadband Internet connection. The router allows one or more traditional desktop computers to tap the broadband connection through wired (usually Ethernet) access while simultaneously making the Internet available wirelessly to one or more laptops.

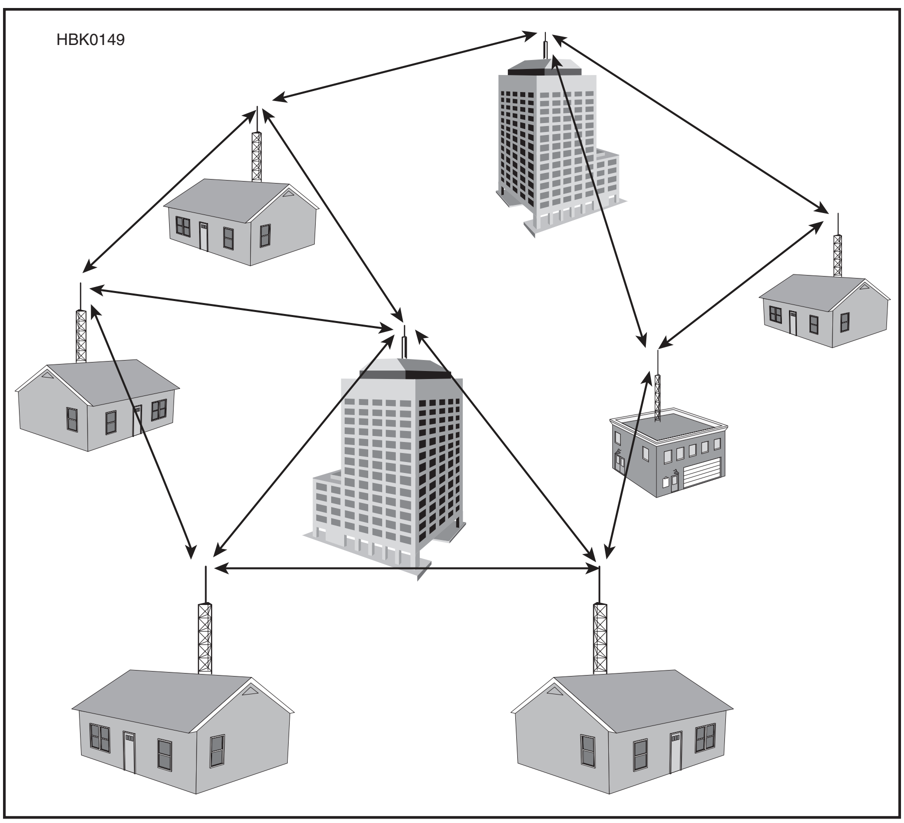

Fig 16 — An HSMM Mesh Network is highly decentralized. Individual mesh stations (nodes) act as repeaters to transmit data from nearby nodes. If one node drops out of the network, the other nodes will automatically re-route the traffic.

All these home networking devices — routers, wireless access cards, and so on — are unlicensed FCC Part 15-regulated transceivers with RF outputs measured in milliwatts. A number of their channel frequencies overlap two Amateur Radio bands: 2.4 and 5.8 GHz. This means that hams can put them to work as "transceivers" under our Part 97 rules. See **Table 2** for specific frequencies.

By using consumer-grade routers, low-loss coaxial cable and gain antennas, hams can quickly establish high-speed, long-distance wireless networks on these 2.4 or 5.8 GHz frequencies. This type of operating is referred to as *high speed multimedia*, or *HSMM*.

With HSMM amateurs have the opportunity to operate several different modes at the same time, and usually do. HSMM is generally IP-based, and given enough bandwidth, radio amateurs have the capability to do the same things with HSMM that are done on the Internet.

• *Audio*: This is technically digital voice, since it is two-way voice over an IP (VoIP) network similar to EchoLink and IRLP networks used to link many Amateur Radio repeaters over the Internet. (VoIP is covered in a later section.)

• *Video*: Motion and color video modes, are called amateur digital video (ADV). This is to distinguish it from digital amateur television (DATV). DATV uses hardware digital coder-decoders (CODEC) to achieve relatively high-definition video similar to *entertainment quality TV*. The usual practice in

Table 2
Wireless Network Frequencies in Amateur Bands

Channel	*Center Frequency*	*Channel*	*Center Frequency*
1	2.412 GHz	132	5.660 GHz
2	2.417 GHz	136	5.680 GHz
3	2.422 GHz	140	5.700 GHz
4	2.427 GHz	149	5.745 GHz
5	2.432 GHz	153	5.765 GHz
6	2.437 GHz	157	5.785 GHz
		161	5.805 GHz
		165	5.825 GHz

Fig 18 — RP connector adapters.

HSMM radio is to use a far less expensive (often free) PC-based software video CODEC to achieve *video communications quality* signals in much smaller bandwidths.

• *Text:* Text exchanges via a keyboard are often used in HSMM radio, but they are similarly called by their Internet or packet radio name: *Chat mode*, and if a server is available on the network, e-mail can also be exchanged.

• *Image*: Image file transfers using file transfer protocol (FTP) can also be done, just as on the Internet.

• *Motion video*: FTP of MPEG files can provide one-way video streaming of short video clips.

• *Remote control*: Individual devices or even complete stations can be remotely controlled.

• *Mesh networking*: A mesh is a wireless cooperative communication infrastructure in which each station functions as a relay, allowing the entire network to cover a large area. See **Fig 16**. This type of infrastructure can be decentralized (with no central server) or centrally managed (with a central server). Both are relatively inexpensive and very reliable. Individual mesh stations (nodes) act as repeaters to transmit data from nearby nodes. The reliability comes from the fact that each node is connected to several other nodes. If one node drops out of the network, due to hardware failure or any other reason, its neighbors simply find another route. Capacity can be increased by simply adding more nodes.

5.1 A Basic HSMM Radio Station

For the sake of simplicity, we'll discuss an HSMM setup with two stations operating in a host/client configuration. See **Fig 17**.

At the time of this writing, the most popular wireless router for HSMM applications is the Linksys model WRT54GL. It is a combination unit consisting of a wireless access point (AP) or hub coupled with a router. As with other routers, your host PC or laptop connects directly to it using a standard Ethernet cable. If the PC is also connected to the Internet, then it may also perform the function of a *gateway*.

The WRT54GL is a *Linux*-based model that supports firmware upgrades. HSMM-active amateurs have been creating their own WRT54GL firmware to support special applications (such as mesh networking). They are effectively "modifying" the WRT54GL in ways Linksys could not have imagined! You do not have the use a WRT54GL to explore HSMM, however. Any wireless router will do. The advantage of the WRT54GL is only that it is widely available and easily modifiable.

The first step in configuring your router for HSMM is to disconnect both flexible antennas that came with the unit and replace them with a high-gain directional antenna system. To connect a gain antenna, you are going to be become familiar with RP (reverse polarity) connectors. These connectors appear to be male connectors on the outside, but they have a socket rather than a pin for the center conductor. RP connectors are used by the manufacturers to discourage Part 15 owners from using the equipment in ways for which it was not WiFi certified.

As licensed radio amateurs, we can modify the system to accomplish our specific requirements within the amateur bands. To connect coaxial cable for an external antenna, you can use an adapter or short jumper cable assembly with appropriate connectors. The adapter shown in **Fig 18** has an RP connector on one end and a standard SMA connector on the other.

There are often two antenna ports on wireless devices. These are used for *receive space diversity*. The wireless device will normally automatically select whichever antenna is receiving the best signal at any specific moment. Which do you connect to?

The transmitted signal from the wireless router always goes out the same antenna port. It does not switch. In other words, most wireless devices use space diversity on the receive side and not on transmit. Some access points/wireless routers will allow you to manually

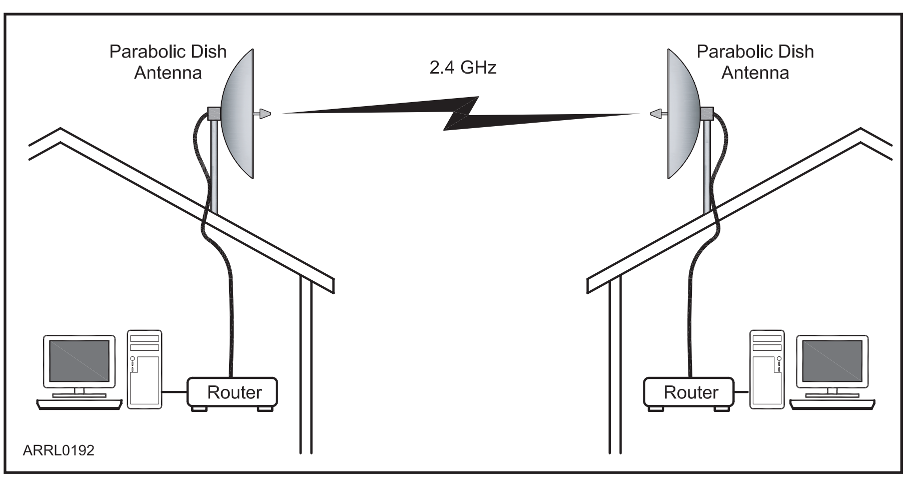

Fig 17 — This is a simplified diagram of a typical HSMM link between two stations. Note that high gain parabolic dish antennas are being used in this example.

(via software) select the antenna port that is used for transmission. When there is no obvious choice, you will need to find some means of detecting which antenna is the transmit antenna port with RF output power present. That is the port to connect to your gain antenna.

Be sure to use low-loss coaxial cable, and keep the run as short as possible. Coaxial cable loss at these frequencies can be quite high, so you are often better off mounting the router directly at the antenna, connecting to it through a very short length of cable. From there you can run the Ethernet cable back to your computer.

SOFTWARE CONFIGURATION

You will need to use either the network configuration software from the router manufacturer or the configuration tool that is part of your operating system. Some routers offer user-friendly access through Internet browsers, which is particularly convenient. Regardless of the approach, the goal is to access and change your router's settings.

SSID: The AP/wireless router host software is provided with an *SSID* (Service Set Identifier) that many Part 15 stations turned off for somewhat higher security. But radio amateurs should leave it ON. Enter your call sign as the SSID and use it for the station identification. It constantly broadcasts your call thus, providing automatic and constant station identification. There are 32 characters available for use in this field so more information such as your group's name can be entered too, including spaces and punctuation. If the router asks if you want to enable the broadcast, click YES. (Note that SSID in the HSMM world has a somewhat different meaning than SSID in the packet radio community. Among packet users, SSID is defined as Secondary Station Identifier.)

ESSID: Some manufacturers use this term in place of SSID to put emphasis on the fact that the SSID is the name for your *network,* not for a specific wireless AP/router.

Access Point Name: When this field is made available (by default is it blank) it is for you to enter a description. This may be handy if you have deployed more than one AP in your network all with your call sign as the SSID. It would allow you to tell them apart. Otherwise, just leave it blank.

Channel: To avoid interfering with other services as much as possible, we need to also look at channel selection. Most HSMM activity is concentrated on 2.4 GHz, using channels 1 through 6, which are within the 2.4 GHz ham allocation.

It is probably best to avoid channel 6. It is the most common manufactures default channel setting and 80% or more of your neighbors will be using it for their household wireless local area network (WLAN). Channel 1 is used by most of the remaining manufacturers as their default channel, so avoid that too. The result is most radio amateurs use channels 3 or 4 depending whether there is a WISP (Wireless Internet Service Provider) operating in their area. Often a WISP will use one of these intermediate channels with a highly directive antenna for back-haul or other purposes. If so, you may wish to coordinate with the WISP and arrange to use some other channel rather than the one specifically used by the WISP. It is not a perfect solution because of all the overlap, but it is a good faith effort to keep most of your stronger signal out of anyone's home, business or governmental WLAN traffic.

WEP: This stands for Wired Equivalent Privacy. In spite of all the horror stories you may have read in the press, this encryption method provides more than adequate means to economically achieve authentication and thus keep the vast majority of free-loaders off your network. If you live in the country you may not need to enable this capability. In an urban environment, it is probably a good thing to do so that you need not constantly monitor every bit of traffic coming over the network to ensure that it originates from an Amateur Radio station. Mixing traffic with another service that shares the same frequency band is not a generally accepted practice except in times of emergency. Therefore, it is often necessary for HSMM radio stations to encrypt their transmissions. This is not to obscure the meaning of the transmission or hide the information. In amateur HSMM applications, the purpose of using WEP is only to block access by non-hams. Amateur HSMM networks openly publish their encryption keys for other hams to use.

Most wireless routers will allow for the use of multiple WEP keys, typically up to four. This will allow you to configure the device so that different client stations have different access authority. For example, club members may have one level of access, while a visiting radio amateur may be given a lesser access. Most HSMM radio groups have just one WEP key and everybody gets that one.

Remember that when it comes to the length of the WEP or other key used, our main purpose is to provide a simple and economical means of authentication already available on the wireless devices. In other words, it is to ensure that only Part 97 stations and not Part 15 stations auto-associate or auto-connect with our HSMM radio node. The shorter the WEP key, the better. This makes it easy to use and remember. During early HSMM radio experimenting around the year 2000, the shortest possible key (5 characters) was used: HSMM-

Authentication Type: Some routers will ask for the type of authentication you want to use such as *shared key*, *open system*, and *both*. Click on SHARED KEY because you will be sharing the WEP/WPA key with any and all radio amateurs who wish to access your HSMM radio node.

*DHCP***:** Some routers will ask if you want Dynamic Host Configuration Protocol enabled. This is the function that assigns IP addresses. Unless you have another source of the DHCP function on your network, you will want to ENABLE this function.

Antenna Selection: A few wireless routers with dual antennas will ask you select an antenna. The default is normally receive space diversity. Because we are going to connect an outside gain antenna, you want to make a selection. Otherwise, you will need to identify which antenna is the actual transmit antenna and connect the feed line to that port, as discussed previously.

Mac Address Filter: Some wireless routers will allow for this security measure, but it is troublesome to administer it, so it is recommended that you not bother enabling this function. Use WEP or some other method of encryption using the guidelines discussed previously.

Output Power: Some wireless routers will allow you to set this power level, often up to 100 mW. As with all other radio amateur operations use only the minimum power needed to accomplish your mission.

THE FAR END OF THE LINK

The computer at the client end of the HSMM link need only have a wireless networking adapter, not a separate router. These transceivers/wireless adapter cards usually come in three forms:

1) One form is called a PC card. Earlier these were called PCMCIA cards, but more recent terminology is to simply call them laptop PC cards.

2) Another type of transceiver/adapter comes with a USB interface, such as the one shown in **Fig 19**. This is often considered a superior interface for most HSMM stations. The reason for this has nothing to do with the quality of the transceiver, but rather the fragile nature of the tiny connectors found on PC cards. They are not really designed for frequent plugging and unplugging. Without extreme care, they can be easily torn out.

3) Linksys and other manufactures also produce similar cards for the

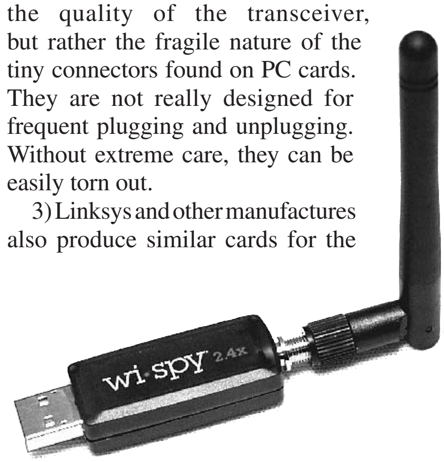

Fig 19 — At the client end of the HSMM link, a simple wireless adapter will do. This USB model allows the user to remove the flexible antenna.

expansion slot on the rear of your desktop PC too.

Regardless of the device you choose, it must have an antenna that is removable or has an external antenna port of some type.

To connect to the AP/wireless router in an HSMM radio network, the wireless computer user(s) at the far end must exit ad-hoc mode and enter what is called the *infrastructure mode*, in their operating software. Infrastructure mode requires that you specify the radio network your computer station is intended to connect to (the host station's call sign), so set your computer to recognize the SSID you assigned to the AP/wireless router to which you wish to connect.

As described previously, you may need to use an adapter to connect the card or interface antenna connector to the coaxial cable running to the antenna. At the other end, most 2.4 GHz antennas come with a standard female N-series connector.

Team up with a nearby radio amateur to test. Do your initial testing in the same room together making sure the link-up is working. Then as you increase distances going toward your separate station locations, you can coordinate using a suitable local FM simplex frequency. You will increasingly need this communication to assist with directional antenna orientation as you get farther apart.

5.2 Running High Power

It is tempting for some radio amateurs to think that if they run higher power they will get better range out of their HSMM radio station. This is not always the case. There are many factors involved in range determination when operating at 2.4 or 5.8 GHz. The first and most significant of these is the lay of the land (topology) and path obstructions. Running additional power is unlikely to correct for either of these impediments.

Second, running higher power to improve signal link margins often requires that this be done at both ends of the link to obtain meaningful results.

Third, most RF amplifiers for use with 802.11 are of the BDA (bidirectional amplifier) type, such as the one shown in **Fig 20**. They amplify both the incoming signal and the outgoing signal, and to get maximum effectiveness out of such devices they must be mounted as close as possible to the antenna.

Fig 20 — A 2.4 GHz bidirectional amplifier.

Fourth, 802.11 signals from such inexpensive broadband devices often come with significant sidebands. This is not prime RF suitable for amplification. A tuned RF channel filter should be added to the system to reduce these sidebands and to avoid splatter.

Also, if your HSMM radio station is next door to an OSCAR satellite ground station or other licensed user of the band, you may need to take extra steps in order to avoid interfering with them, such as moving to channel 4 or even channel 5. In this case a tuned output filter may be necessary to avoid not only causing QRM, but also to prevent some of your now amplified sidebands from going outside the amateur band, which stops at 2450 MHz.

Do not use higher power as a substitute for higher antenna gain at both ends of the link. Add power only after all reasonable efforts have been taken to get the highest possible antenna system gain and directivity.

5.3 HSMM Antenna Options

There are a number of factors that determine the best antenna design for a specific HSMM radio application. Most commonly, HSMM stations use horizontal instead of vertical polarization because it seems to work better. In addition, most Part 15 stations are vertically polarized, so this is sometimes thought to provide another small barrier between the two different services sharing the band. With multipath propagation is it doubtful how much real isolation this polarization change actually provides.

More importantly, most HSMM radio stations use highly directional antennas (**Fig 21**) instead of omnidirectional antennas. Directional antennas provide significantly more gain and thus better signal-to-noise ratios, which in the case of 802.11 modulations means higher rate data throughput and greater range. Higher data throughput, in turn, translates into more multimedia radio capability. Highly directional antennas also help amateurs avoid interference from users in other directions.

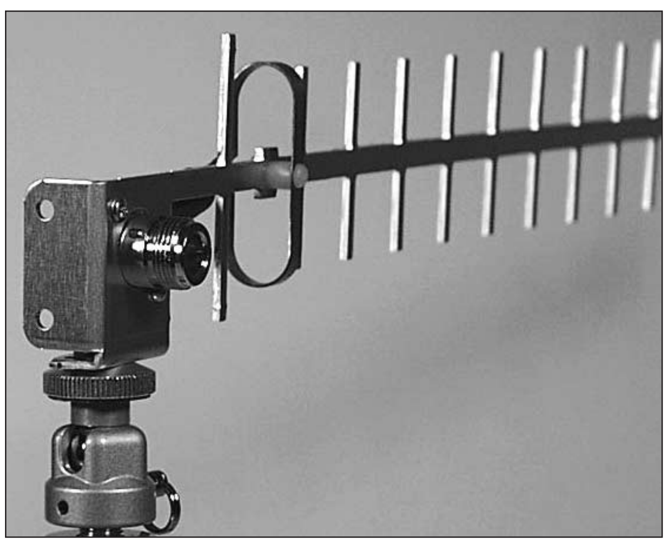

Fig 21 — Directional antennas, such as this MFJ 2.4 GHz Yagi, are best for HSMM links.

6 Automatic Link Establishment (ALE)

Automatic link establishment (*ALE*) is a "system" that incorporates digital techniques to establish a successful communications link. ALE is not a digital mode *per se*, but the primary software is sound card based.

To understand ALE, consider how HF propagation changes. A band can open over a particular path one hour, but close the next. A signal may be fully readable on one band, but inaudible on another. With that in mind, imagine two stations, one in New York City and one in Los Angeles, that wish to communicate on the HF bands (see **Fig 22**). Basic propagation guidelines give a general idea of which bands might be best, but operators at both ends of the path will have to experiment, calling on several bands until they find a frequency that supports a transcontinental path.

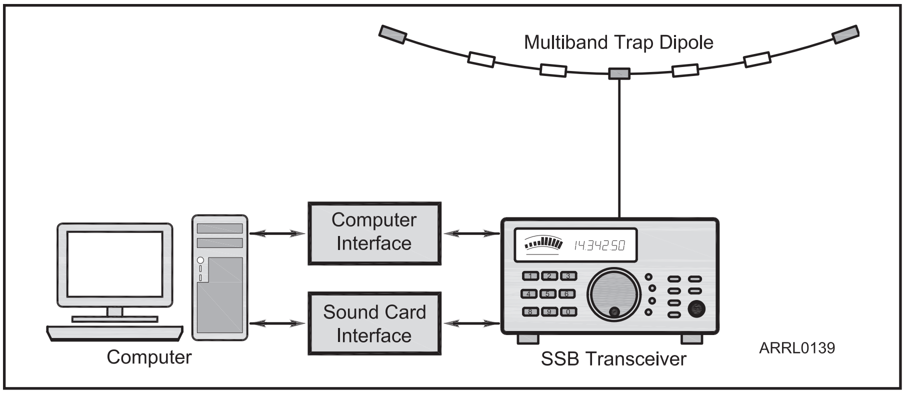

Fig 23 — An optimum ALE station has a computer-controlled transceiver and a multiband antenna system. In this example, the station is using a multiband trap dipole antenna. Note that a separate interface is needed between the computer and transceiver for frequency control.

ALE automates this process, allowing the stations under computer control to automatically call each other on different bands until contact is established. In the example, the operator in New York City initiates the ALE call by entering the call sign of the receiving station into his ALE software, along with some likely frequencies. The call sign becomes the *Selective Call*, or SELCAL. The ALE software switches the transceiver to the first frequency in the queue and transmits the chosen SELCAL. If there is no response, the software will step the transceiver to another frequency and try again.

At the same time, the receiving station in Los Angeles has been automatically scanning specific ALE frequencies, listening for its call sign. When it finally decodes something that resembles its call sign, it stops scanning and listens since the ALE data burst contains several repetitions of the call. When it finally decodes its full call sign, the Los Angeles station transmits a "handshake" signal to the New York City station to confirm that a link has been established. All scanning stops and the ALE software sounds an alarm to call the operators to their stations.

ALE is a good tool for HF net operation in both routine and emergency applications where many stations may be standing by for calls. Think of ALE as being analogous to a VHF FM scanning transceiver with a digitally coded squelch that automatically scans several repeaters. Unless it hears the correct code, the radio remains silent. With amateur ALE you can call individual stations or entire groups of stations.

In addition to its application as a selective calling system for HF voice, ALE can also be used as a pure digital mode for exchanging text and images.

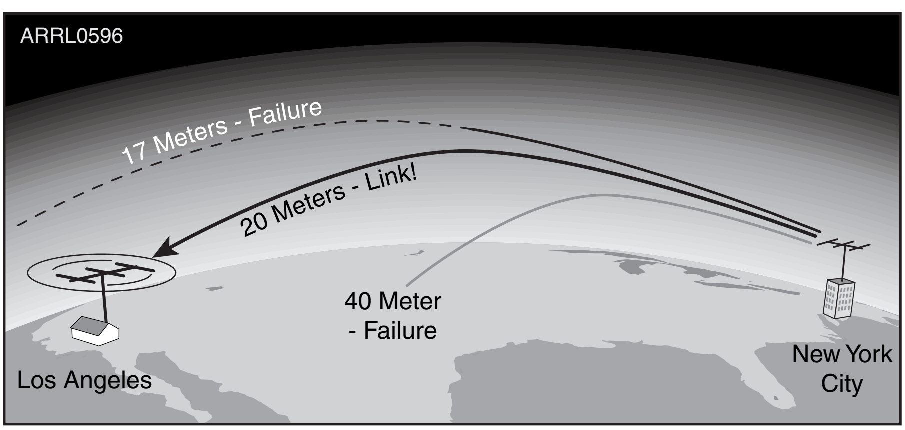

Fig 22 — The ALE calling station typically scans through a list of frequencies, calling on each one until a path to the receiving station is found.

AMATEUR ALE SOFTWARE

ALE has been used by the military and government for years, and hams have generally adopted the government ALE standards: FED-STD-1045 or MIL-STD 188-141. In 2001, ALE captured the attention of the Amateur Radio world with the release of *PCALE* software by Charles Brain, G4GOU. *PCALE* not only controls your transceiver, it uses your computer sound card to decode ALE signals and generate them for transmission. You'll find *PCALE* software on the Web at **www.hflink.com**. You must join the free HF Link group on Yahoo at **tech.groups.yahoo.com/group/hflink** before you can download the software.

From the standpoint of assembling a station for ALE, it works best when two conditions are satisfied: 1) you have a multiband HF antenna system; the more bands the better; and 2) your HF transceiver can be controlled by computer.

Although you can use ALE on just one frequency, the real power of ALE comes into play when your station is able to operate on multiple bands under computer control. A typical setup is shown in **Fig 23** and includes a radio control interface as well as a sound card interface. With *PCALE* controlling your radio, it will automatically change frequencies, monitoring as many bands and frequencies as you have programmed into the software. A list of ALE channels and information on ALE nets is available from **www.hflink.com**. Note that all ALE transmissions use USB.

7 D-STAR

The D-STAR digital protocol began in 2001 as a project funded by the Japanese Ministry of Posts and Telecommunications to investigate digital technologies for Amateur Radio. The research committee included representatives of the Japanese Amateur Radio manufacturers and the Japan Amateur Radio League (JARL). JARL is the publisher of the D-STAR protocol.

All radio manufacturers are free to develop D-STAR equipment, but at the time of this writing ICOM is the only company that has done so for the US amateur market. Although ICOM may develop D-STAR protocol enhancements peculiar to the function of its hardware, ICOM does not "own" the original D-STAR protocol.

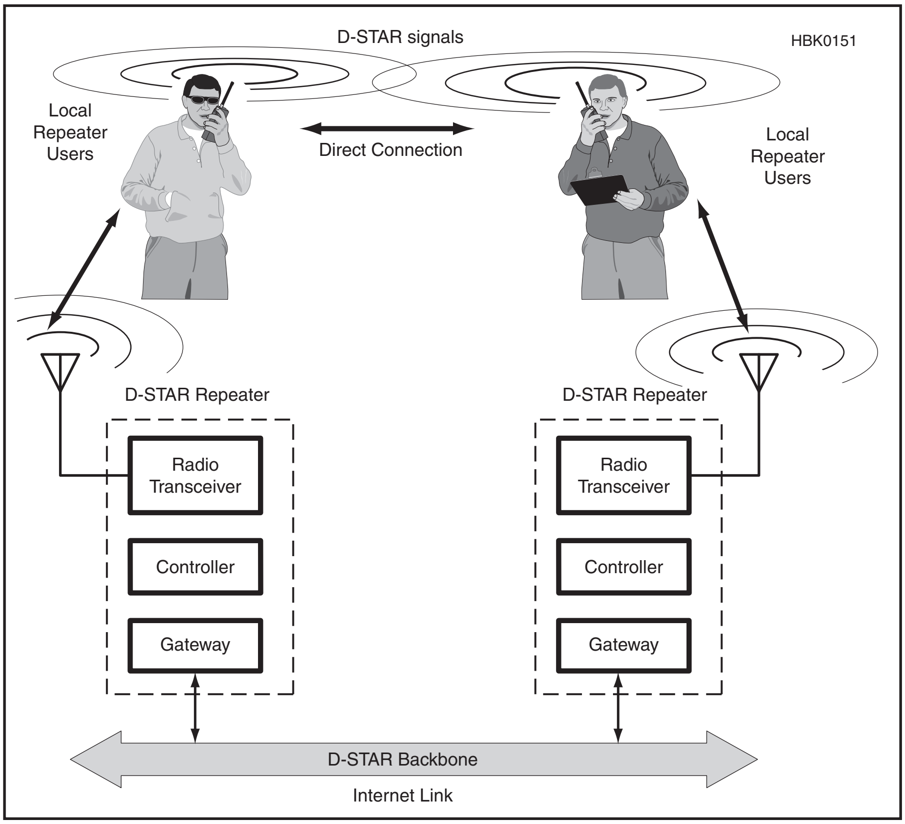

Fig 24 — A D-STAR network can take several forms. D-STAR compatible transceivers can communicate directly (simplex) or through a D-STAR repeater for wide coverage.

7.1 What is D-STAR?

The primary application of D-STAR is digital voice, but the system is capable of handling any sort of data — including text, voice or images.

As shown in **Fig 24**, a D-STAR network can take several forms. D-STAR compatible transceivers can communicate directly (simplex), or through a D-STAR repeater for wide coverage. D-STAR signals cannot be repeated through traditional analog repeaters without modification.

The D-STAR system carries digitized voice and digital data, but does the job in two different ways. There is a combined voice-and-data mode (DV) and a high-speed data-only stream (DD). From the perspective of the D-STAR user, data and voice are carried at different rates and managed in different ways, but over the air they are transported as bit streams.

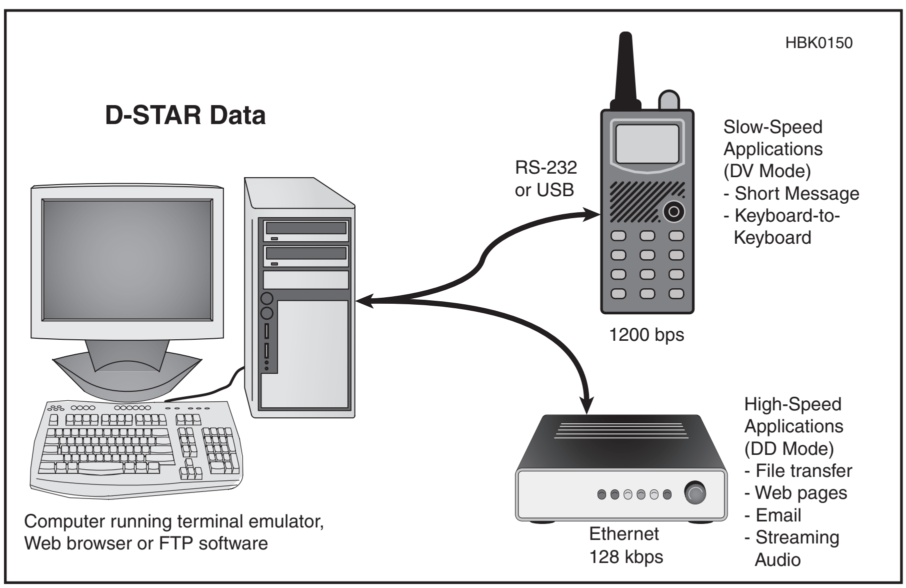

Fig 25 — Radios that support DV voice and data present an RS-232 or USB 2.0 interface to the user.

7.2 Digital Voice and Low-Speed Data (DV)

The D-STAR codec digitizes analog voice by using the AMBE 2020 codec. AMBE stands for Advanced Multiple Band Encoding and 2020 designates the particular variation used by D-STAR.

AMBE can digitize voice at several different rates. The D-STAR system uses a 2.4 kbit/s rate that offers a good compromise between intelligibility and the speed at which data must be transmitted via the radio link. In addition, AMBE adds information to the voice data that allows the receiving codec to correct errors introduced during transmission. The net result is that the digitized voice stream carries data at a rate of 3.6 kbit/s.

Interleaved with the digitized voice information, D-STAR's DV mode also carries 8-bit digital data at 1200 bit/s. This data is used for synchronization in the D-STAR protocol with the remaining bandwidth available for use by the radio manufacturer. ICOM uses the remaining bandwidth to carry repeats of the D-STAR RF header, the 20 character front-panel message, and serial data as described below.

Radios that support DV voice and data provide an RS-232 or USB 2.0 interface to the user as shown in **Fig 25**. (The RS-232 interface is restricted to RxD, TxD and ground — "three-wire" connection.) Any computer terminal or

program that can exchange data over those types of interfaces can use D-STAR's DV mode capabilities as a "radio cable."

Because D-STAR's DV mode handles the data stream in an unmodified "raw" format, it is up to the equipment or programs that are exchanging data to manage its flow. ICOM requires the sender and receiver to perform flow control by using special data characters. This is called *software flow control or xon/xoff flow control*.

7.3 High-Speed Data (DD)

D-STAR's high-speed data mode is called *D-STAR DD*. This mode does not digitize the analog voice signal. The data-only packets sent over the RF link at a raw data rate of 128 kbit/s half-duplex, but since that includes the packet header and the delay between packets, the *net data rate* is somewhat lower. As with the DV mode, data is transmitted without modification so flow control is left to the applications on each end. Radios supporting DD mode communications may also support DV mode.

Users connect to a radio supporting DD mode with an Ethernet interface via the usual RJ-45 modular jack found on computer networking equipment. The DD mode interface looks to computer equipment just like a customary IP network connection. Specifically, the DD mode interface is an Ethernet "bridge." This allows Web browsers and other Internet software to run normally, as if they were connected to standard computer network.

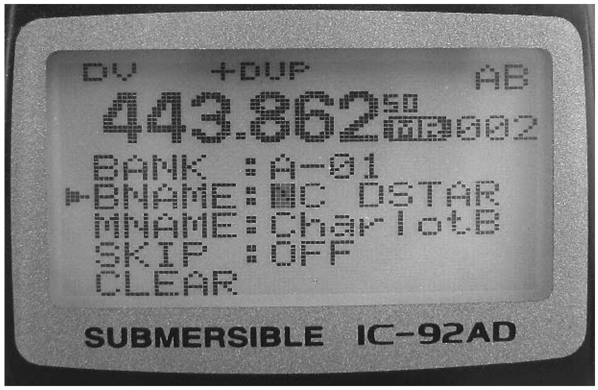

Fig 26 — The ICOM IC-92AD is a 2 meter/70-cm handheld with D-STAR functionality.

The net data rate of DD mode is comparable to or better than a high-speed dial-up Internet connection. Any streaming media mode that will run over dial-up Internet will likely perform well over D-STAR.

With its high signaling rate and 130-kHz bandwidth, FCC regulations restrict D-STAR DD operating to the 902 MHz and higher bands.

7.4 D-STAR Radios

When this book went to press, ICOM was the only manufacturer offering D-STAR compatible radios and repeaters. So, by default, the focus of any discussion of D-STAR hardware centers on ICOM gear.

ICOM D-STAR radios are available as mobile/base transceivers and also as handheld transceivers. With the exception of the ID-1 base/mobile transceiver, which operates at 1.2 GHz, ICOM D-STAR transceivers are designed to operate at 2 m, 70 cm or both. ICOM D-STAR transceivers also support both digital and analog operation, which means that they can also be used for traditional analog FM communication as needed. An example is shown in **Fig 26**.

To determine the most appropriate D-STAR radio for an application, the first step is to understand the requirements:

- Is DD mode operation required (high-speed data)? If so, the only radio supporting DD mode is the ID-1.
- What bands are required? That will depend on activity in your area. If data is to be transmitted while in motion, higher frequencies will result in fewer transmission errors, improving the net data exchange rate. (Note: DD operation is only permitted on 902 MHz and higher.)
- Is high-power required? Using higher power base/mobile radios will result in stronger signal strengths and fewer data transmission errors.
- If data is to be transmitted, what data interface does the computer have?
- Error correction for low-speed data (DV mode) is the responsibility of the data communications programs used to exchange data. Make sure to carefully evaluate the software you intend to use.

More information about D-STAR may be found in the **Digital Modes** and **Repeaters** chapters.

8 APCO-25

Unlike D-STAR, which is a digital standard devised by and for Amateur Radio, APCO-25 was developed specifically for local, state and federal public safety communications. "APCO" is the Associated Public-Safety Communications Officials, originally an association of police communication technicians, but now a private organization. APCO has a technical standards group responsible for planning the future needs of police (and more recently public safety) users. It was through this group that a standard for advanced narrow-band digital communications (voice or data) was developed. This standard is known as APCO Project 25, APCO-25, or simply P25.

The overall purpose of the APCO-25 standard is to make it possible for governments to shift from analog to digital communications with the least difficulty possible. This means placing a great deal of emphasis on *backward compatibility* (P25 radios include analog operation and newer P25 technology doesn't render older technology instantly obsolete) and *interoperability* (the ability for all P25 radios to communicate with each other). In the public safety world, interoperability is a key selling point so that various services and agencies can coordinate efforts.

8.1 APCO-25 and Amateur Radio

When this section was written, no one was making APCO-25 transceivers specifically for the Amateur Radio market, but that hasn't stopped some hams from exploring this mode. Because APCO-25 is an open, published standard, it *is* legal for Amateur Radio, but the trick is finding the means to adapt commercial APCO-25 gear to ham purposes.

The present-day Amateur Radio APCO-25 world looks a lot like the analog FM community in the early 1970s. Back then, none of the Amateur Radio manufacturers were making FM transceivers or repeaters. Hams were forced to modify existing commercial FM gear, which typically consisted of transceivers that had seen duty in police cruisers, taxi cabs and so on. Many of the FM "gurus" in those days were individuals who were employed by two-way radio service shops. These hams had easy access not only to test equipment, but also to the knowledge of how to modify commercial transceivers for ham applications. They built the first Amateur Radio FM repeaters by repurposing commercial two-way radio transmitters and receivers.

Amateur Radio APCO-25 enthusiasts today are treading the same path taken by analog

FM pioneers more than 30 years ago. They are modifying commercial APCO-25 equipment for Amateur Radio and setting up APCO-25 repeater systems. Thanks to online sites such as eBay, it is relatively easy to track down surplus APCO-25 transceivers. Manufactured in both handheld and mobile configurations, these rigs are available for either VHF or UHF.

Modifying commercial APCO-25 radios has become a software hacking game. Since most functions of these radios are software defined, you can change their operating characteristics (including frequencies) with a computer and a compatible interface.

The first step is to obtain the programming software, which can be different for every brand. Some manufacturers provide programming software if you purchase the radio as new equipment. Others are highly restrictive and will not provide their software under any conditions. Motorola, a popular brand among amateur P25 users, uses different programs for every transceiver model. The programming software must be purchased from them at a cost of $250 to $300. To reprogram the Motorola transceivers (as well as many other brands), you may need a hardware device that is sometimes referred to as a Radio Interface Box, or RIB.

The downside of using surplus commercial equipment is that it can be expensive. At the time of this writing, used handheld APCO-25 transceivers were selling for as much as $700 at Internet auction sites. Modified APCO-25 repeaters can cost several thousand dollars.

The cost hurdle hasn't deterred hams from setting up APCO-25 networks. There are more than a dozen amateur APCO-25 repeater systems in operation throughout the United States. Many of these repeaters operate in mixed mode — analog and digital. Others are digital only. The ability to operate in mixed modes is one of the strengths of Amateur Radio APCO-25. An APCO-25 repeater, for instance, can support digital voice and data with APCO-25 transceivers, but can still relay analog FM traffic.

More ham-related programming information is available at the following Web sites, although it applies specifically to Motorola transceivers: **www.batlabs.com/newbie.html** and **www.batlabs.com/flash.html.**

8.2 The APCO-25 Standard

APCO-25 is comprised of a "Suite of Standards" that specifies eight open interfaces between the various components of a land mobile radio system.

- *Common Air Interface* (CAI) standard specifies the type and content of signals transmitted by compliant radios. One radio using CAI should be able to communicate with any other CAI radio, regardless of manufacturer
- *Subscriber Data Peripheral Interface* standard specifies the port through which mobiles and portables can connect to laptops or data networks
- *Fixed Station Interface* standard specifies a set of mandatory messages supporting digital voice, data, encryption and telephone interconnect necessary for communication between a Fixed Station and P25 RF Subsystem
- *Console Subsystem Interface* standard specifies the basic messaging to interface a console subsystem to a P25 RF Subsystem
- *Network Management Interface* standard specifies a single network management scheme which will allow all network elements of the RF subsystem to be managed
- *Data Network Interface* standard specifies the RF Subsystem's connections to computers, data networks, or external data sources
- *Telephone Interconnect Interface* standard specifies the interface to Public Switched Telephone Network (PSTN) supporting both analog and ISDN telephone interfaces.
- *Inter RF Subsystem Interface* (ISSI) standard specifies the interface between RF subsystems which will allow them to be connected into wide area networks.

You'll find more details about the APCO-25 standard on the Web at **www.apcointl.org/frequency/project25/index.html**.

8.3 APCO-25 "Phases"

The APCO-25 rollout was planned in "phases." Phase 1 radio systems operate in 12.5 kHz analog, digital or mixed mode. Phase 1 radios use continuous 4-level FM (C4FM) modulation for digital transmissions at 4800 baud and 2 bits per symbol, which yields 9600 bits per second total throughput. It is interesting to note that receivers designed for the C4FM standard can also demodulate the compatible quadrature phase shift keying (CQPSK) standard. The parameters of the CQPSK signal were chosen to yield the same signal deviation at symbol time as C4FM while using only 6.25 kHz of bandwidth. This is to pave the way for Phase 2, which is under development. Phase 1 is the current phase in use at the time this book was written and is likely to be in force for a number of years to come.

In a typical Phase 1 radio, the analog signal from the microphone is compressed and digitized by an Improved Multi-Band Excitation, or *IMBE*, vocoder. This is a proprietary device licensed by Digital Voice Systems Corporation. The IMBE vocoder converts the voice signal from the microphone into digital data at a rate of 4400 bit/s. An additional 2400 bit/s worth of signaling information is added, along with 2800 bit/s of forward error correction to protect the bits during transmission. The combined channel rate for IMBE in P25 radios is 9600 bit/s.

P25 radios are able to operate in analog mode with older analog radios and in digital mode with other P25 radios. If an agency wants to mix old analog radios with P25 radios, the system must use a control channel that both types of radios can understand. That means a trunked radio system.

9 HF Digital Voice

While D-STAR is the dominant digital voice/data system on the VHF+ bands, three very different systems can be found in operation on the HF bands. One uses dedicated hardware while the other two rely on sound cards and software. All require HF SSB transceivers, although they could just as easily be used on VHF SSB (or even FM) as well.

9.1 AOR and AMBE

The AOR Corporation was the first ham manufacturer to arrive on the scene with an HF

Fig 27 — The AOR ARD-9800 digital voice modem.

digital voice and data "modem" in 2004. The fundamental design is based on a Vocoder protocol created by Charles Brain, G4GUO. His protocol involves the use of Advanced Multi-Band Excitation, better known as *AMBE,* a proprietary speech coding standard developed by Digital Voice Systems. Brain's protocol operates at 2400 bit/s, with Forward Error Correction added to effectively produce a 3600 bit/s data stream. This data stream is then transmitted on 36 carriers, spaced 62.5 Hz apart, at 2 bits/symbol, 50 symbols/s using QPSK. This gives the protocol a total RF bandwidth of approximately 2250 Hz (compared to 2700-3000 Hz for an analog single sideband transmission).

The AOR units, such as the ARD9800 (**Fig 27**), are designed to be as "plug and play" as possible. You simply plug your microphone into the front-panel jack and then plug the modem into the microphone input of your transceiver. A front panel switch selects digital encoding or analog transmission, so the unit can be kept in the line when not used for digital conversations. On the receive side, the modem automatically detects the synch signal of an AMBE transmission and switches to digital mode automatically. In addition to voice, the AOR modems can send digital data (typically images).

AOR ON THE AIR

AOR digital voice is clear and quiet, an unusual thing to hear on an HF frequency. Tune around 14.236 MHz and you're likely to hear AOR AMBE signals. They sound like rough hissing noises.

During *QST* Product Review testing in 2004, the ARRL Lab discovered that decoding was solid down to about 10 dB S/N. Digital voice is an all-or-nothing proposition, however, and below that level the signals begin to break up. The result is absolute silence during those periods. Interference to the received signal produced a similar outcome.

The common approach on the air is to begin the conversation in analog SSB, then switch to digital. Each transmission starts with a one-second synch burst after the push-to-talk button is pressed. If the other station misses the sync signal, the audio doesn't decode and the transmission sounds like analog white noise. This means that for successful communication you must be on the correct frequency and ready to receive at the beginning of the transmission. However, if there is fading or interference during the synch transmission, you may be unable to decode the signal that follows.

A few additional steps will improve odds of success with AOR modems.

- Make sure that both stations are on exactly the same frequency, within about 100 Hz.
- Set IF receive filters to 3 kHz or wider.

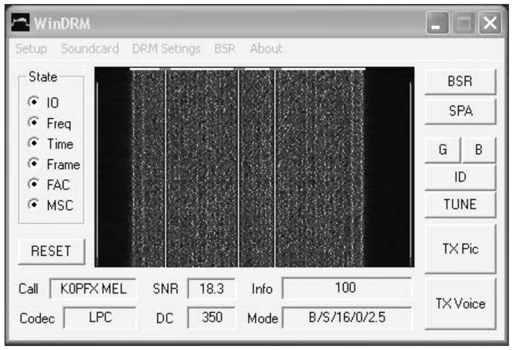

Fig 28 — *WinDRM* digital voice/image software.

- Don't overdrive the modem audio input.
- Turn off transceiver speech compression.
- Don't overdrive the radio. If the ALC meter shows any activity, turn down the output from the modem.

Transceiver duty cycle will be substantially higher when you're operating digital voice compared to normal SSB. To avoid damaging your radio, it is a good idea to reduce your output by 25 to 50%.

9.2 WinDRM

WinDRM began with *Dream*, a piece of open-source software developed by Volker Fisher and Alexander Kurpiers at the Darmstadt University of Technology in Germany. It was designed to decode Digital Radio Mondiale (DRM), a relatively new digital shortwave broadcast format. On the air, DRM presents as a wide, roaring signal. A commercial DRM signal is capable of carrying high-quality audio along with text and occasional images.

DRM uses Coded Orthogonal Frequency Division Multiplexing (COFDM) with Quadrature Amplitude Modulation (QAM). COFDM uses a number of parallel subcarriers to carry all the information, which makes it a reasonably robust mode for HF use.

Not long after *Dream* debuted, Francesco Lanza, HB9TLK, began adapting it for Amateur Radio. He redesigned *Dream* to support amateur DRM transmission and reception within a 2.5-kHz SSB transceiver bandwidth. That meant sacrificing some audio quality, along with the ability to simultaneously send images.

As the name implies, *WinDRM* is a *Windows* application (**Fig 28**). It is designed to use a computer sound card or on-board sound chipset to send and receive amateur DRM. Activity is primarily on HF. In addition to the software, you need a radio, computer and one of the sound-card interfaces discussed earlier in this chapter. Start by downloading and installing the *WinDRM* software at **n1su.com/windrm/download.html**. On this same Web page you will find documentation that explains the installation and operation.

To receive amateur DRM, all you need is a cable between the audio output of your radio and the LINE INPUT of your sound card. You may need to get into your sound card control software and boost the LINE INPUT gain. Using the *Windows* audio mixer, which you can access within *WinDRM*, bring up the **Recording Control** panel and make sure LINE is selected and that the "slider" control is up. If the *WinDRM* waterfall display is too bright, reduce the gain control.

Transmitting with *WinDRM* is somewhat more complicated in terms of your station setup, especially if you have only one sound card. The audio output from your sound card must be applied to your headset or PC speakers for receiving, but the *same* output must also feed your transceiver for transmitting (see **Fig 29**) so a switch for the audio output is needed. The easier, more elegant approach is to use two separate sound cards as shown in **Fig 30**. The second sound card doesn't need to be high-end; you can use an inexpensive USB sound card for this application.

As with the AOR modems, be careful not to overdrive your transceiver. If you see the ALC meter indicating excessive drive, reduce the sound card audio output.

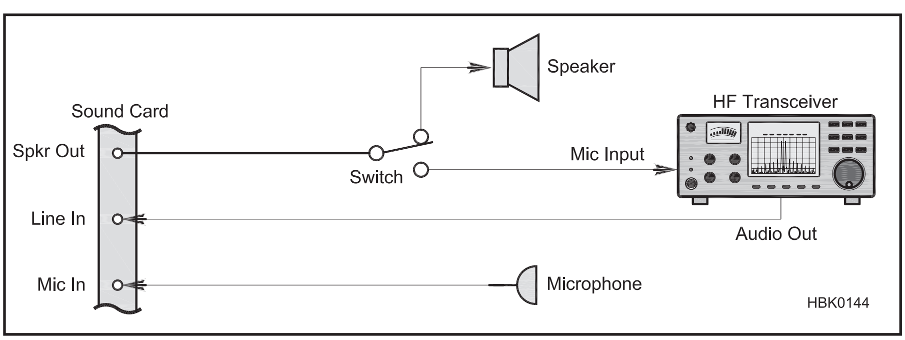

Fig 29 — The single sound card approach to using *WinDRM* or *FDMDV* requires the means to switch the audio stream when switching from transmit to receive.

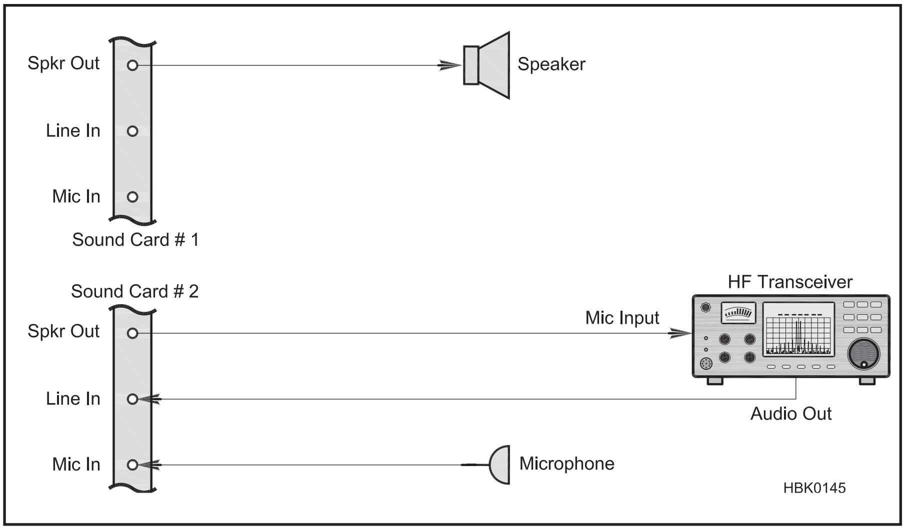

Fig 30 — The most elegant, easy-to-operate solution for *WinDRM* and *FDMDV* is to use two sound cards — one to process the received signal and the other to generate the transmit signal.

9.3 FDMDV: Frequency Division Multiplex Digital Voice

Like *WinDRM*, *FDMDV* is a software approach to digital voice that uses the sound card for processing the received signal and generating the transmit signal. The *FDMDV* software is available at **www.n1su.com/fdmdv**, along with the documentation. Station setup and hardware requirements are identical to *WinDRM*.

The advantages of FDMDV compared to WinDRM are twofold: 1) FDMDV can decode signals at substantially weaker levels and 2) FDMDV occupies an effective bandwidth of only 1100 Hz.

A popular frequency for HF digital voice is 14.236 MHz, USB. Information about digital voice nets and activity on other bands is available from **www.n1su.com** and other Web sites.

10 EchoLink, IRLP and WIRES-II

Worldwide communication on HF requires reliable propagation and more substantial radio and antenna requirements than a basic VHF FM setup. By using Internet links instead of HF radio links, a ham with a modest radio (even a handheld transceiver) can reliably communicate with stations hundreds or even thousands of miles away at any time of the day or night.

The most common form of amateur Internet linking involves the exchange of audio using *VoIP* — Voice over Internet Protocol — technology. This is the same technology used by Internet telephone services, and by online voice "chat" applications such as *Skype*, *TeamSpeak* and others. Three versions of Amateur Radio voice linking have become popular in the US: EchoLink, IRLP and WIRES-II.

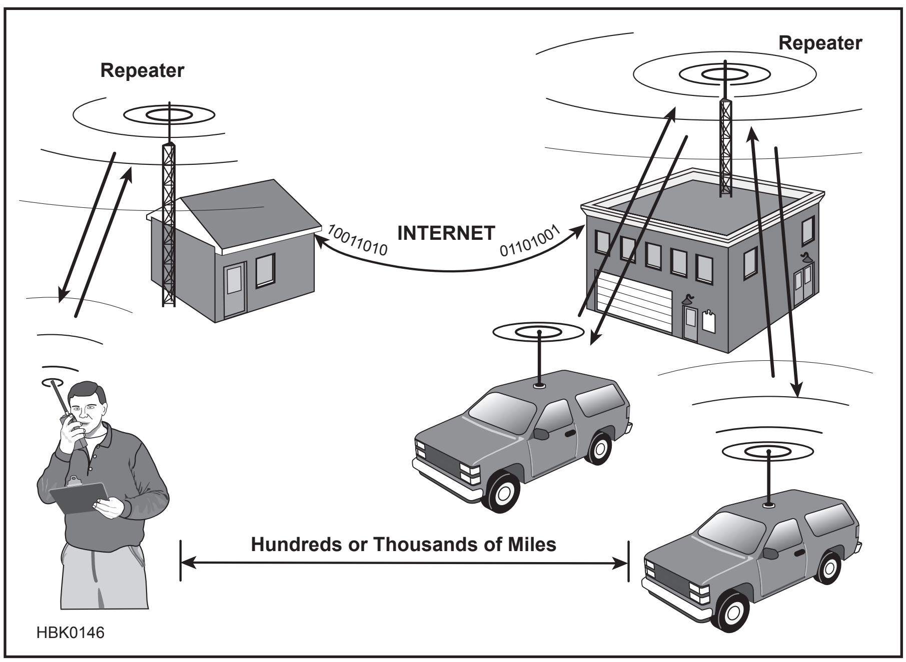

Fig 31 — The Internet VoIP link allows repeater users to speak with other amateurs who may be transmitting through other repeaters.

10.1 EchoLink

EchoLink software, developed by Jonathan Taylor, K1RFD, is designed for *Windows* PCs, but there is a Mac version as well. With the software installed on a sound-card-equipped computer, any ham can create an EchoLink *node* that others can access by radio. Hams can also join the network directly without using radios. They simply plug microphone/headsets into their computers.

Each EchoLink node is assigned a number that can be up to six digits in length. RF users access the EchoLink network by first sending the DTMF code required to activate the link on a repeater or simplex node. Of course, this requires a transceiver equipped with a DTMF keypad. Once the link is up, they use the keypad again to transmit the number of the EchoLink repeater, link or user they wish to contact.

Hams who access the network directly (without a radio) select the person or system they wish to contact by simply clicking on its name in the software listing. The EchoLink network maintains continuously updated databases on several servers that indicate node and user locations and operational status. The network servers also support *conferencing* where many users can "meet" and speak together, either by direct access or via radio.

EchoLink supports communication among three different source groups:

• *Repeaters*: This is typically a VHF/UHF FM repeater with a computer at the site and a

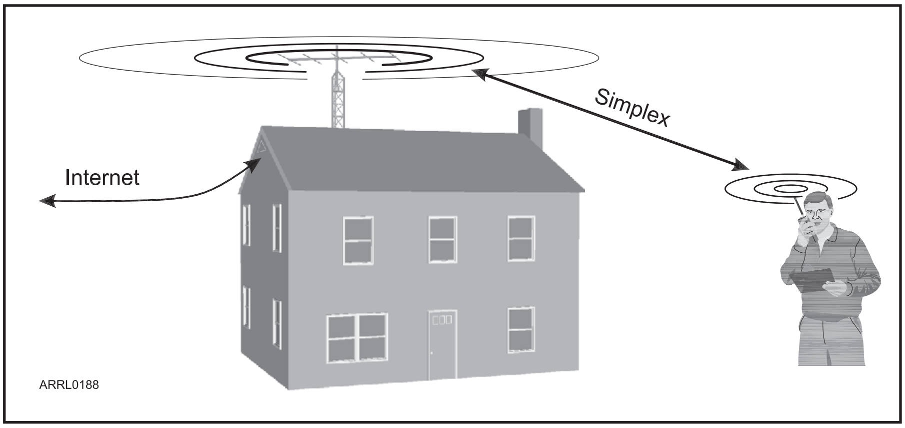

Fig 32 — A typical Echolink simplex node.

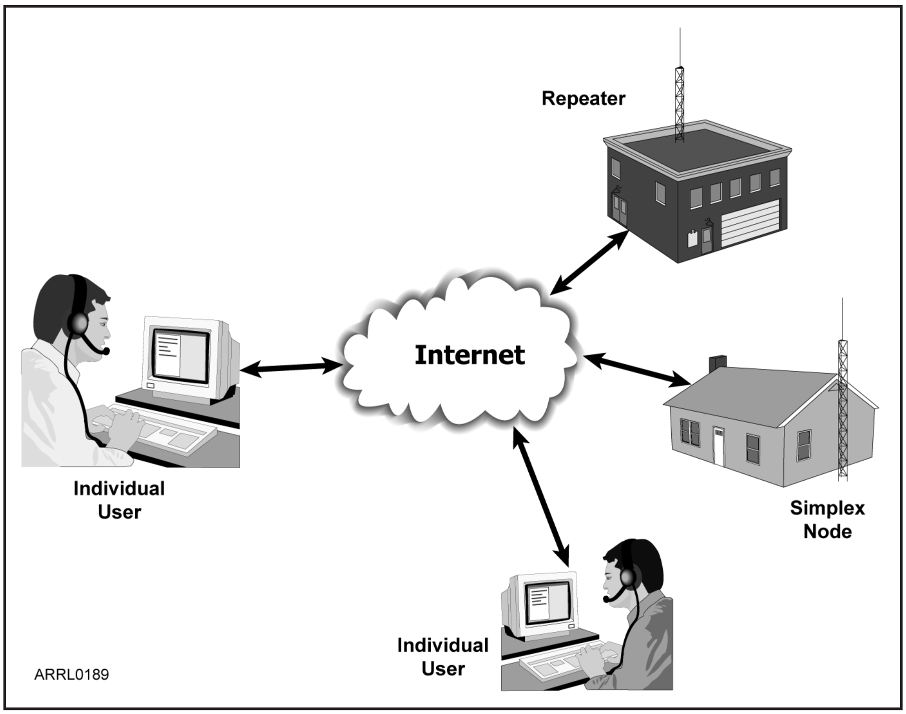

Fig 33 — For some EchoLink users, there is no radio involved (at least at their end of the conversation).

VoIP connection to the Internet via EchoLink. When the Echolink function is switched on, audio from the repeater is available on the EchoLink network, and vice versa. The Internet VoIP link allows repeater users to speak with other amateurs who may be transmitting through other repeaters, or who may be linking directly (see **Fig 31**).

• *Links*: Similar to repeater nodes, but operating on simplex frequencies without full repeater functionality (see **Fig 32**). These are typically FM transceivers connected to computers. Depending on the station setup, their coverage can be confined to a neighborhood, or it may encompass an entire county.

• *Users*: This is strictly a computer-to-computer VoIP connection (see **Fig 33**) with no RF involved. In other words, the operator is sitting in front of his computer wearing a microphone/headset.

All of the interfacing on the "RF side" of EchoLink is handled by connections to the computer sound card and serial port with a sound-card interface used to switch the radio between transmit and receive — exactly the same setup used by sound card based digital communications such as PSK

ECHOLINK SECURITY

Before being granted access, every ham who establishes an EchoLink node, or who connects to the network directly, must provide positive proof of identity and license during the EchoLink registration process. Details are available from **www.echolink.org/authentication**. After having been validated, each EchoLink node or user must provide a password, along with his or her call sign, to log in. Each time a connection is made for a QSO, the EchoLink servers verify both the sender and the receiver before communication can begin. Hams who use their radios to connect to the EchoLink network through a repeater or a simplex node do *not* have to be validated or provide a password. This is only necessary for the repeater or link stations, or for those who connect directly.

It is possible to configure EchoLink to accept connections only from certain types of stations: repeaters, links, users or all three. You can also set up a list of any number of "banned" call signs, which will not be allowed access. In addition, you can block or accept connections according to their international call sign prefix, in order to comply with reciprocal control-operator privileges or third-party traffic restrictions.

In Sysop mode, by default, EchoLink announces each station by call sign when the station connects. (The user can program a voice or CW ID that is generated automatically when needed.) The EchoLink software automatically generates detailed logs and (optionally) digital recordings of all activity on the link.

Unlike software such as e-mail programs, file-sharing programs and Web browsers, EchoLink does not have any way to pass files or "attachments" that might harm your computer. There are no known cases of EchoLink accepting or spreading a computer virus. Of course, any PC connected to the Internet should always be protected by some sort of Internet security hardware or software.

10.2 IRLP

IRLP stands for Internet Radio Linking Project. Like EchoLink, IRLP uses the Internet to establish VoIP links. The difference is that IRLP only permits access via RF nodes at repeaters or on simplex frequencies (all IRLP nodes are interlinked via a central Internet server). You must use a radio to access the IRLP network.

A typical IRLP node consists of a transceiver that is connected to the Internet through dedicated IRLP hardware and software. This requires a *Linux* computer running IRLP software and an IRLP interface board, or a turnkey "embedded" IRLP unit that combines the *Linux* computer, IRLP software and interface in a single package (**Fig 34**). The IRLP software controls the VoIP audio stream using carrier operated squelch (COS) or continuous tone coded subaudible squelch signals (CTCSS) from the transceiver. When COS is present, the computer detects it through the IRLP interface board.

The operator connects to the IRLP network (at a repeater, for instance) using DTMF sig-

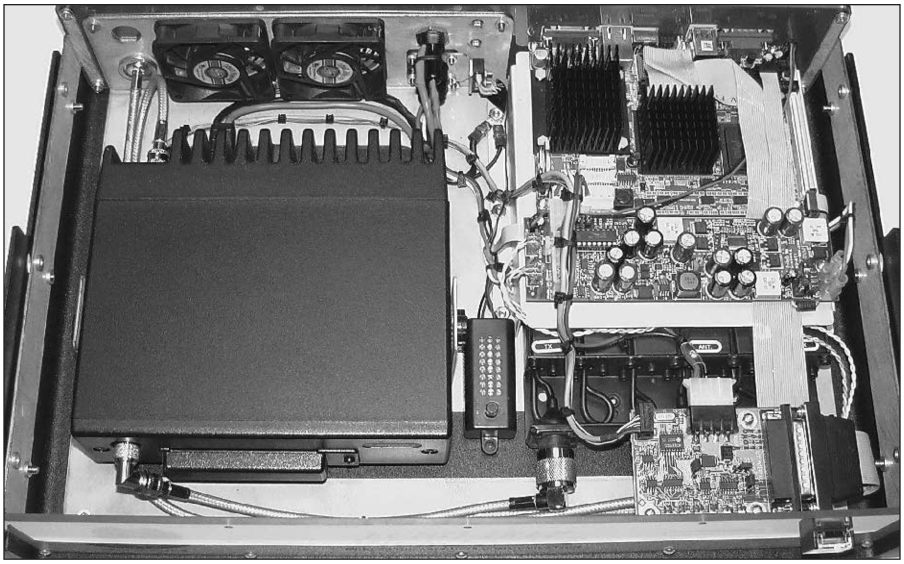

Fig 34 — The Micro-Node MN-3200 is an embedded IRLP node that combines the *Linux* computer, IRLP software and interface, along with a 70 cm repeater and duplexer in a single package.

nals sent over the radio. As with EchoLink, this means that the operator must have a radio with a DTMF keypad. The actual access code is determined by the owner of the node. The user sends the correct DTMF sequence to bring up the IRLP connection, then sends the sequence of the distant node he wishes to contact. That might be a repeater in another state or a distant simplex node. You can view a list of current IRLP nodes at **status.irlp.net/statuspage.html**.

Here is an example of a typical IRLP connection:

• Press the transceiver PTT and identify your station. For example, "This is WB8IMY, Steve in Wallingford, Connecticut, USA connecting to node 8880."

• Next, press *#8880* (node 8880 in this example) on the DTMF keypad, release PTT and wait for the node connect announcement. The announcement indicates that your audio is now reaching the distant node. You can call a specific person, or just ask if anyone is around to chat.

• When finished, key PTT , make an announcement such as "WB8IMY releasing node 8880" and then press *#73* on the DTMF keypad to disconnect. The IRLP node will announce the disconnect and the node may now connect to a different node, reflector, or it will stand by awaiting another user.

It is interesting to note that there is a project underway (known as *EchoIRLP*) to bridge the IRLP and EchoLink networks.

10.3 WIRES-II

WIRES-II — Wide-Coverage Internet Repeater Enhancement System — is a VoIP network created by Vertex Standard (Yaesu). It is functionally similar to IRLP (including management via a central Internet server), but nodes and repeaters are connected via a Vertex Standard HRI-100 interface and a computer running under the *Windows* operating system. Vertex Standard transceivers are *not* required for WIRES-II communication, but as with IRLP, all access must be via RF.

There are two WIRES-II operational configurations using home stations (simplex nodes), repeaters or a combination of the two:

SRG — Sister Radio Group. You operate within WIRES-II in a small (10 node maximum) network that is ideal for closed-group operations. Within the network, all nodes operate using the same repeater node list, so you can link only to stations within this 10 node network. Because there are only ten nodes maximum, access to any of these nodes is possible using a single DTMF tone when calling. At the beginning of each transmission, this single DTMF tone locks communication between the calling node and the called node, but local (non-linked) transmissions are also possible, simply by omitting the DTMF tone at the beginning of the transmission.

FRG — Friends Radio Group. You may call any repeater registered with the WIRES-II FRG server. In the case of FRG operation, a six-digit DTMF code is required for access, and once the link is established this code need not be sent again (this is called the LOCK mode), unless the operator wants the ability to make non-linked transmissions (UNLOCK mode), in which case the six-digit code must be sent at the beginning of each transmission (using the DTMF Autodial feature of the transceiver, for example). Group calling to preset 10-repeater B, C, and D lists is also possible.

SRG is similar in philosophy to the local FM voice repeater where you tend to talk to the same group on a regular basis. FRG is similar in concept to IRLP, linking together a worldwide group of repeaters and base stations.

11 Glossary of Digital Communications Terms

***AFSK* —** Audio frequency shift keying, a method of digital modulation in which audio tones of specific frequencies are used with an SSB voice transceiver.

***ALE* —** Automatic link establishment. A process in which stations under computer control automatically call each other on different bands until contact is established.

AMBE — Advanced multi-band excitation, a proprietary speech coding standard developed by Digital Voice Systems.

***AMTOR* —** Amateur teleprinting over radio, an amateur radioteletype transmission technique employing error correction as specified in several ITU-R Recommendations M.476-2 through M.476-4 and M.625.

APRS — Automatic Packet (or Position) Reporting System. A system of sending location and other data over packet radio to a common Web site for tracking and recording purposes.

***ARQ* —** Automatic Repeat reQuest, an error-sending station, after transmitting a data block, awaits a reply (ACK or NAK) to determine whether to repeat the last block or proceed to the next.

***ASCII* —** American National Standard Code for Information Interchange, a code consisting of seven information bits.

***AX.25* —** Amateur packet-radio link-layer protocol. Copies of protocol specification are available from ARRL HQ.

***Baud* —** A unit of signaling speed equal to the number of discrete conditions or events per second. (If the duration of a pulse is 20 ms, the signaling rate is 50 bauds or the reciprocal of 0.02, abbreviated Bd).

***Baudot code* —** A coded character set in which five bits represent one character. Used in the US to refer to ITA2.

***BER* —** Bit error rate.

***BERT* —** Bit-error-rate test.

Checksum — The output of an algorithm that allows the receiving system to detect errors in transmitted data.

***CLOVER* —** Trade name of digital communications system developed by Hal Communications.

***Collision* —** A condition that occurs when two or more transmissions occur at the same time and cause interference to the intended receivers.

***CRC* —** Cyclic redundancy check, a mathematical operation. The result of the CRC is sent with a transmission block. The receiving station uses the received CRC to check data integrity.

Data modes — Computer-to-computer communication, such as by **packet radio** or **radioteletype (RTTY)**, which can be used to transmit and receive computer characters, or digital information.

Digipeater — A station that relays digital data transmissions.

DRM — Digital Radio Mondiale, a digital modulation method used to transfer audio and data on HF bands.

EchoLink — A system of linking repeaters and computer-based users by using the Internet (also see **VoIP**).

***Eye pattern* —** An oscilloscope display in the shape of one or more eyes for observing the shape of a serial digital stream and any impairments.

***FEC* —** Forward error correction, an error-control technique in which the transmitted data is sufficiently redundant to permit the receiving station to correct some errors.

FSK — Frequency shift keying, a method of digital modulation in which individual bit values are represented by specific frequencies. If two frequencies are used, one is called *mark* and one *space*.

GPS — Global Positioning System

***G-TOR* —** A digital communications system developed by Kantronics.

***Hellschreiber* —** A facsimile system for transmitting text.

HSMM — High speed multimedia, a digital radio communication technique using spread spectrum modes primarily to simultaneously send and receive video, voice, text and data.

IEEE 802.11 — An IEEE standard for spread spectrum communication in the 2.4 GHz band at 1 Mbit/s and 2 Mbit/s data rates. 802.11 is also used as a general term for all spread spectrum devices operating under Part 15. (Also see **WiFi**.)

IEEE 802.11a — An IEEE standard for spread spectrum communication in the 5.8 GHz band at 6, 12, 16, 24, 36, 48, and 54 Mbit/s data rates.

IEEE 802.11b — An IEEE standard for spread spectrum communication in the 2.4 GHz band at 5.5 and 11 Mbit/s data rates in addition to being backward compatible with DSSS at 1 and 2 Mbit/s specified in 802.11.

IEEE 802.11g — An IEEE standard for spread spectrum communication in the 2.4 GHz band at 6, 12, 16, 24, 36, 48, and 54 Mbit/s data rates in addition to being backward compatible with DSSS at 1, 2, 5.5, and 11 Mbit/s specified in 802.11b.

IEEE 802.11n — An IEEE standard specifying data rates up to 250 Mbit/s and being backward compatible with 802.11a and 802.11g.

IEEE 802.16 — An IEEE standard specifying wireless last-mile broadband access. Also known as **WiMAX**.

IRLP — Internet Radio Linking Project, a system that uses the Internet to establish **VoIP** links among amateur stations who access the system via RF nodes at repeaters or on simplex frequencies.

***Linux* —** A free Unix-type operating system originated by Linus Torvalds, et al. Developed under the GNU General Public License.

MFSK — Multi-frequency shift keying.

***MFSK16* —** A multi-frequency shift communications system

***Modem* —** Modulator-demodulator, a device that connects between a data terminal and communication line (or radio).

***MSK* —** Frequency-shift keying where the shift in Hz is equal to half the signaling rate in bits per second.

***MT63* —** A keyboard-to-keyboard mode similar to PSK31 and RTTY.

Multiple protocol controller (MPC) — A piece of equipment that can act as a **TNC** for several **protocols**.

***Null modem* —** A device to interconnect two devices both wired as DCEs or DTEs; in EIA-232 interfacing, back-to-back DB25 connectors with pin-for-pin connections except that Received Data (pin 3) on one connector is wired to Transmitted Data (pin 3) on the other.

***Packet radio* —** A digital communications technique involving radio transmission of short bursts (frames) of data containing addressing, control and error-checking information in each transmission.

***PACTOR* —** Trade name of digital communications protocols offered by Special Communications Systems GmbH & Co KG (SCS).

***Parity check* —** Addition of non-information bits to data, making the number of ones in a group of bits always either even or odd.

Position encoder — A device that receives data from a GPS receiver, assembles APRS packets from the data and creates modulated signals for use by the transmitter.

***Project 25* —** Digital voice system developed for APCO, also known as P25.

***Protocol* —** A formal set of rules and procedures for the exchange of

information within a network.

***PSK* —** Phase-shift keying.

***PSK31* —** A narrow-band digital communications system.

Radioteletype (RTTY) — Radio signals sent from one teleprinter machine to another machine. Anything that one operator types on his teleprinter will be printed on the other machine. Also known as narrow-band direct-printing telegraphy.

Sound card — A computer sound processing device that may be included on the motherboard, as a plug-in card, or as a separate external device.

Sound card interface — A device used to connect a computer sound card to a transceiver to provide TR switching and transmit/receive audio connections.

***Throb* —** A multi-frequency shift mode like MFSK16.

***TNC* —** Terminal node controller, a device that assembles and disassembles packets (frames); sometimes called a PAD.

Terminal unit (TU) — An interface used between an old teletype unit and a transceiver.

Turnaround time — The time required to reverse the direction of a half-duplex circuit, required by propagation, modem reversal and transmit-receive switching time of transceiver.

VoIP — Voice over Internet Protocol, a technology used to exchange audio information over the Internet.

Waterfall — A continuously scrolling display where the software processes and displays signatures of all signals detected within the bandwidth of the received audio signal.

WEP — Wired Equivalent Privacy. An encryption algorithm used by the authentication process for authenticating users and for encrypting data payloads over a WLAN.

WEP Key — An alphanumeric character string used to identify an authenticating station and used as part of the data encryption algorithm.

WiFi — Wireless Fidelity. Refers to products certified as compatible by the WiFi Alliance. See **www.wi-fi.org**. This term is also applied in a generic sense to mean any 802.11 capability.

***WiMAX* —** Familiar name for the IEEE 802.16 standard.

Wireless router — A low-power wireless device that manages data flow on a network that can include desktop or laptop computers, broadband Internet connections, printers and other compatible devices.

WIRES-II — Wide-Coverage Internet Repeater Enhancement System, a **VoIP** network created by Vertex Standard (Yaesu) that is functionally similar to **IRLP**.

WISP — Wireless Internet Service Provider

WLAN — Wireless Local Area Network.

WSJT — A suite of computer software for VHF/UHF digital communication including meteor scatter and moonbounce work.

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Contents

Image Communications

This supplement covers two popular communication modes that allow amateurs to exchange still or moving images over the air. Advances in technology have made image communications easier and more affordable, resulting in a surge of interest.

The first part of this chapter, by Tom O'Hara, W6ORG, describes fast-scan television (FSTV), also called simply amateur television (ATV). ATV is full-motion video over the air, similar to what you see on your broadcast TV. Because of the wide bandwidth required for ATV signals, operation takes place on the UHF and microwave bands.

The second part of this chapter, prepared by Dave Jones, KB4YZ, describes slow-scan television (SSTV). Instead of full motion video, SSTV requires a few seconds per picture. SSTV is a narrow bandwidth image mode that is popular on the HF bands using SSB voice transceivers. SSTV operation can take place on FM, repeaters and satellites too. Unless otherwise noted, references to other chapters refer to chapters in the print version of the *ARRL Handbook*.

1 Fast-Scan Amateur Television Overview

Fast-scan amateur television (FSTV or just ATV) is a wideband mode that is based on the analog *NTSC* (National Television System Committee) standards used for broadcast television in the US for many years, before most broadcasters switched to digital transmission in 2009. Analog AM and FM ATV use standard NTSC television scan rates. It is called "fast scan" only to differentiate it from slow-scan TV (SSTV) or digital TV (DTV). In fact, no scan conversions or encoders/decoders are necessary with analog ATV.

Any standard TV set capable of displaying analog NTSC broadcast or cable TV signals can display the AM Amateur Radio video and audio signals. New consumer digital television (DTV) sets sold in the US are designed to receive high definition television (HDTV) broadcasts since the changeover in 2009 using the 8-VSB (8-level Vestigial Side Band) standard from the Advanced Television Systems Committee (ATSC). DTV televisions will also include analog AM and Digital Cable (D-CATV) TV channel tuners per FCC Rule 15.118(b). It is a good idea however, to not dispose of your old analog-only televisions, but keep them for ATV. Analog AM ATV on the 70 cm band will be the primary ATV system for some time given its low cost, size, and ease to get on.

To transmit ATV signals, standard RS-170 composite video (1-V peak-to-peak into 75 Ω) and line audio from home camcorders, cameras, DVD/VCRs or computers is fed directly into a transmitter designed for the ATV mode. The audio goes through a 4.5 MHz FM subcarrier generator in the AM ATV transmitter that is mixed with the video. It is the same for FM ATV, but the sound subcarrier can be anything from 4.5 MHz to 6.8 MHz, with 5.5 MHz typical.

Picture quality is about equivalent to that of a VCR, depending on ATV RF signal level and any interfering carriers. All of the sync and signal-composition information is present in the composite-video output of modern cameras and camcorders. Most camcorders have an accessory cable or jacks that provide separate audio/video (A/V) outputs. Audio output may vary from one camera to the next, but usually it has been amplified from the built-in microphone to between 0.1 and 1 V P-P (into a 10-kΩ load).

1.1 ATV Activities

Amateurs regularly show themselves in the shack, zoom in on projects, show home video recordings, televise ham club meetings and share just about anything that can be shown live or by tape (see **Figs 1** and **2**, and application notes at **www.hamtv.com/info.html**). Whatever the camera "sees" and "hears" is faithfully transmitted, including full motion color and sound information. Computer graphics and video special effects are often transmitted to dazzle viewers. Several popular ATV applications are described in detail later in this chapter.

1.2 Comparing Analog AM, FM and Digital ATV

Receiving ATV using any of the three ATV modes is relatively easy using consumer televisions and receivers directly, or with the addition of an amateur band receive converter (downconverter). Much of the activity in an area depends on the first few hams who experiment with ATV, and on the cost and availability of equipment for others to see their first picture.

Most older analog-only TVs that do not have active channel memory scan setup and

Fig 1 — Students enjoy using ATV to communicate school to school or between classrooms (top). The ATV view shows the aft end of the Space Shuttle cargo bay during a mission (bottom).

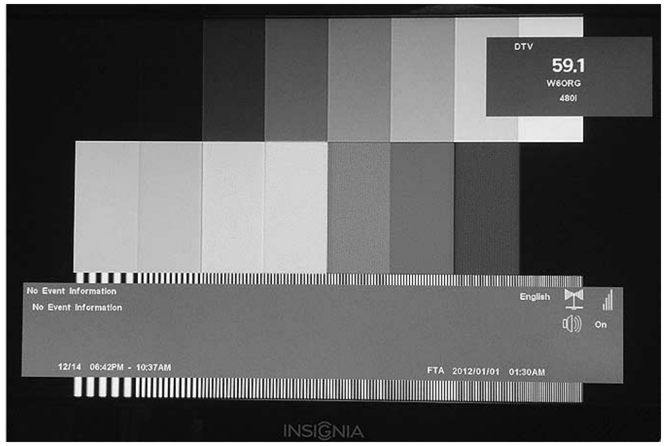


Fig 3 — When the info or display button is pushed on newer digital TV's remote control, the D-CATV channel number may be a Virtual Channel designation from 1 to 999 (and not the actual transmitted channel programmed in the DTV modulator), along with the station call and other information. Channel 59.1 is shown, but the actual transmitter channel was 58 and does not change if the frequency is changed. Analog channels are shown without the decimal point or with a decimal point or dash and a zero. Digital channels are shown with a major number, decimal point or a dash and a minor number. The minor numbers indicate that this channel may have more than one video or program.

Fig 2 — The one-way ATV DX record is held by KC6CCC in San Clemente, California, for reception of 434-MHz video from KH6HME in Hawaii during a tropo opening in 1994. The distance is 2518 miles. See www.hamtv.com/atvdxrecord.html.

don't have video squelch that goes to blank or blue screen when no signal is present are preferred by ATV DXers as they can continuously search or monitor for ATV signals in the snow easily. Newer TV's have an active channel scan setup that searches for analog and digital channels and skips those that are found not to be active. If you have cable, most likely it will have active cable channels 57-60 (direct 70 cm ATV), 3 and 8 (downconverter output) and be available for use on ATV if you have done the setup scan while connected to your cable service. If you do not have a cable service, your TV may or may not let you manually add a channel if no signal is present. You may have to get a local ATVer to send you a signal that is strong enough as you do the channel scan. This will also be the case with over the air digital 8-VSB and cable QAM transmissions.

The frequency reference for an analog AM transmission is the video carrier which is 1.25 MHz up from the lower channel edge. A digital transmission is referenced as the center frequency — for instance, cable channel 57 AM is 421.25 MHz, digital is 423.0 MHz in the same 420-426 MHz range. Note that D-CATV stations can present as Virtual Channels or Logical Channel Numbers which may not be the actual transmitted channel when detected by the TV setup channel scan. If your TV info overlay says you have a valid digital channel 59.1, it could actually be transmitted on a different channel. The station ID, channel and info are transmitted with the video and any text can be programmed into the modulator as seen in **Fig 3** for whatever purpose the cable operator has.

Analog AM ATV on the 70 cm band is the easiest mode. The 70 cm ham band contains the same frequencies as cable channels 57 through 61, so a TV that has an analog cable tuner can be used for receiving ATV signals as well. Simple 70 cm ATV transmitters are available that are low cost, small, and draw less current than the other ATV modes. This is desirable for R/C (radio control), high altitude balloon, rocket and portable emergency communications or public service events. Call letter IDs with 70 cm AM ATV can be seen at much greater range, although with a lot of snow in the picture, and is the favorite of DXers. Adding a linear amplifier requires an initial drive setup so as to keep the video modulation within the linear range.

FM ATV also uses simple transmitters, but most activity is on the 13 cm, 23 cm and 33 cm amateur bands. This is in part because of the wide occupied bandwidth needed for FM ATV signals, and in part because of the availability of receivers originally designed for commercial C-band satellite or unlicensed Part 15 use. The FM receivers have analog A/V outputs that must be connected to a video monitor and not a channel 3 analog RF modulator to a TV in order to see the best picture resolution possible. Less care need be given to driving power amplifiers than when using AM or digital modulation.

Digital ATV (D-ATV) signals using 8-VSB or QAM, can also be received simply by using new televisions in the same manner as analog cable televisions, but the transmitters are complex and currently expensive. Quadrature Phase Shift Keying (QPSK) may also be used but it requires a receiver box that is more common in other parts of the world to receive Digital Video Broadcast — Satellite (DVB-S). D-ATV is still an emerging technology among hams who like to experiment. The

Fig 4 — The Drake DSE24 D-CATV 64-QAM modulator used for cable TV can be adapted for ATV with the addition of linear amplifiers. Maximum output is about –8 dBm which can drive high linearity MMIC, MOSFET and LDMOS amplifiers to usable power levels for ATV on the 70 cm and 33 cm bands. Transverters can be used for operation on higher frequency bands.

cost of board level components and software is coming down and there are cable head-end D-CATV modulators using the North American ITU-T J.83B protocol version of Quadrature Amplitude Modulation (QAM), such as the Drake DSE24, shown in **Fig 4**, that are available for about $1000 and can be used directly on the 70 cm or 33 cm ham band with the addition of very linear amplifiers. Digital transmission requires an MPEG-2 compression and digital transport encoder and a digital RF modulator/exciter. 8-VSB is an amplitude-modulated, 8-level baseband signal that is processed and filtered to occupy 5.38 MHz bandwidth. This signal fits in a standard 6-MHz channel with guard bands. D-CATV QAM also fits in a standard 6-MHz channel. RF amplifiers for DTV are more critical as to drive level, linearity and low intermodulation distortion than with analog AM or FM ATV modes.

A good reference on the technical characteristics of an ATSC 8-VSB transmission can be found in an article by David Sparano entitled "What Exactly Is 8-VSB Anyway?" and available online from **www.broadcast.net/~sbe1/8vsb/8vsb.htm.** 8-VSB and QAM can have a little higher resolution (**Fig 5**) than AM because they do not have a sound subcarrier that limits the video bandwidth. Information on QAM can be found at **www.ni.com/white-paper/3896/en.** D-ATV using QPSK resolution varies trading off with bandwidth, data rate, bit error correction and other factors**.**

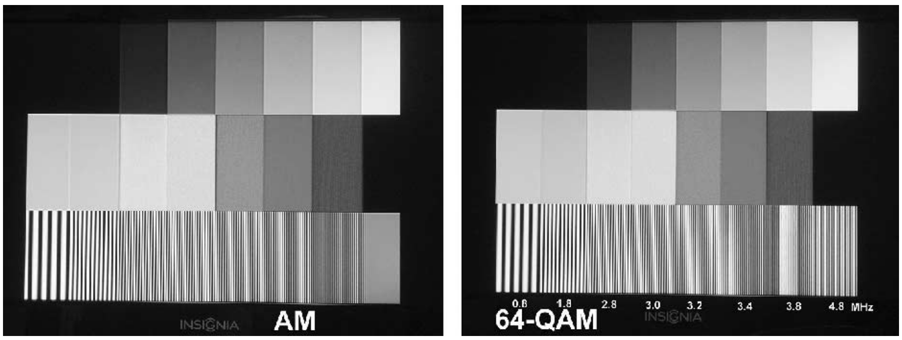


Fig 5 — These two images compare P5 test patterns from an AM analog transmitter and a D-CATV 64-QAM transmitter. The 4.8 MHz multiburst vertical lines can be seen in the 64-QAM 480i picture ,but the AM is rolled off to grey and is limited to resolving the 3.8 MHz burst lines

PICTURE QUALITY

Experimentally, using the US standard, FM ATV gives increasingly better picture-to-noise (snow) ratios than AM analog ATV at receiver input signals greater than 5 µV. That's also about the signal level for the 8-VSB DTV "cliff effect" where the signal disappears. The DTV all-or-nothing cliff effect occurs because the digital signal detector and processing in the receiver require a signal-to-noise ratio (SNR) of at least 15 dB for 8-VSB. Above 15 dB, you get an excellent picture, and at 14 dB SNR — nothing. Other DTV types — D-CATV QAM or Digital Video Broadcast — Satellite (DVB-S) QPSK — are a few dB better in the presence of noise.

Because of the wider noise bandwidth and FM threshold effect, AM analog video can be seen in the noise well before FM and DTV. For DX operation, it has been shown that AM signals are recognizable in the snow (noise) at up to four times (12 dB) greater distance than FM or 8-VSB DTV signals, with all other factors equal. Above the FM threshold, however, FM rapidly overtakes AM. FM snow-free pictures occur above 50 µV, or four times farther away than with AM signals. The crossover point is near the signal level where sound and color begin to appear for AM, FM and 8-VSB systems. 64-QAM pops up snow-free at 20 µV. **Fig 6** compares analog AM, FM and digital ATV picture quality levels across a wide range of received signal strengths.

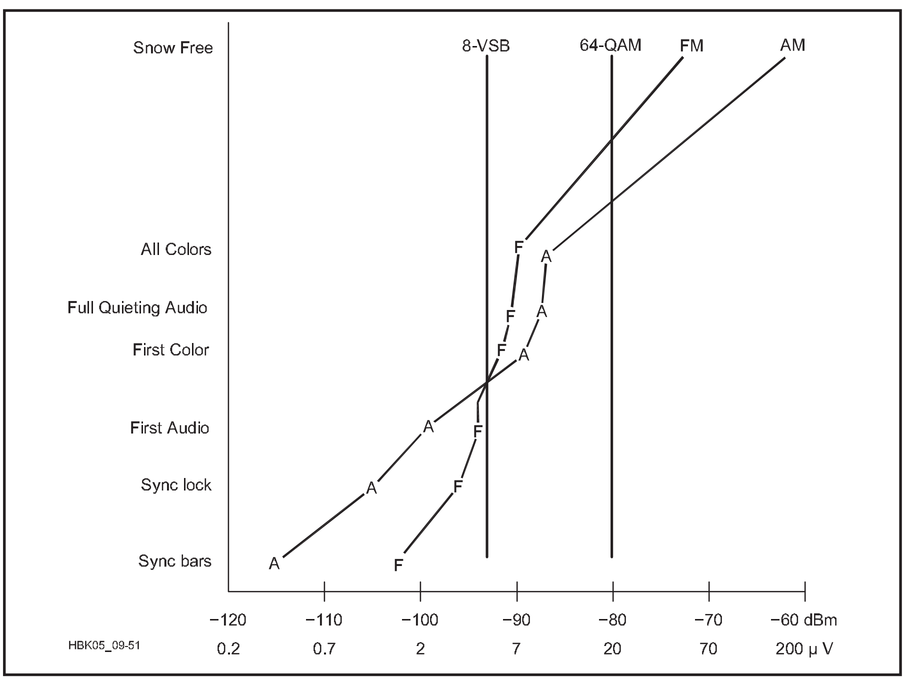


Fig 6 — Four approaches to ATV receiving. This chart compares AM, FM and two digital ATV modes as seen on a TV receiver and monitor. Signal levels are into the same downconverter with sufficient gain to be at the noise floor. The FM receiver bandwidth is 17 MHz, using the US standard. The straight vertical line for DTV around –93 dBm for 8-VSB and –80 dBm for D-CATV 64-QAM illustrates the cliff effect described in the text. QPSK DTV will be somewhere between –80 and –93 dBm depending on the selected bandwidth and other modulation factors.

1.3 How Far Does ATV Go?

The theoretical snow-free line-of-sight distance for 20 W PEP 70 cm analog AM ATV, given 15.8 dBd gain antennas and 2 dB of feed line loss at both ends, is 150 miles. (See **Fig 7**) In practice, direct line-of-sight ATV contacts seldom exceed 25 miles due to the curvature of the Earth with hills and buildings

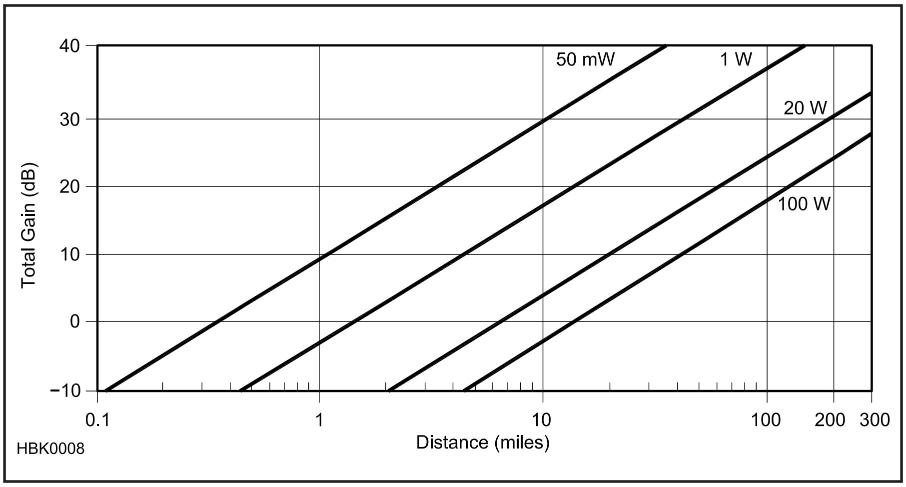


Fig 7 — This graph shows the possible line-of-sight distances for P5 (snow free) video reception for various analog AM ATV transmitter levels in the 70 cm band. Power levels shown are in PEP. The Total Gain is calculated by adding the antenna gain (dBd) for both the receive and transmit antennas and then subtracting the feed line loss (in dB) at both ends. For other bands: 33 cm, subtract 6 dB; 23 cm, subtract 9 dB; and 13 cm, subtract 15 dB. For FM ATV (4 MHz deviation, 5.5 MHz sound), add 12 dB. For ATSC 8-VSB digital TV, the sudden loss of picture "cliff effect" distance is found by adding 26 dB. If the noise figure of the first stage in the downconverter is greater than 2 dB, subtract for each dB over 2. See the example in Table 1.

Table 1
ATV DX Graph Example

Transmit antenna	+10 dBd
Receive antenna	+12 dBd
Transmit feed line	–1 dB
Receive feed line	–2 dB
6 dB noise figure	–4 dB

Total Gain for 70 cm is 15 dB
With 20 W PEP, range is 35 miles (Fig 7)

For 23 cm (–9 dB) gain is 6 dB
With 1 W PEP, range is 3 miles (Fig 7)

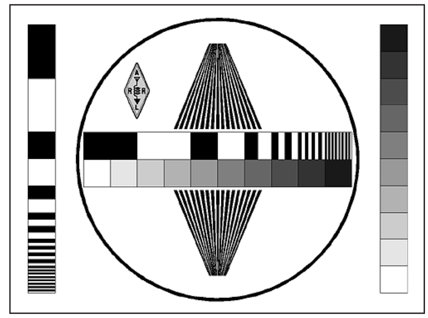
blocking the direct path. Longer distances are possible with over-the-RF-horizon tropo openings, reflections, or through high hilltop repeaters. A 2518-mile reception record is shown in Fig 2. (See the **Propagation of Radio Signals** chapter.)

The antenna is the most important part of an ATV system because it affects both receive and transmit signal strength. For best DX, use low-loss feed line and a broadband high-gain antenna, up as high as possible.

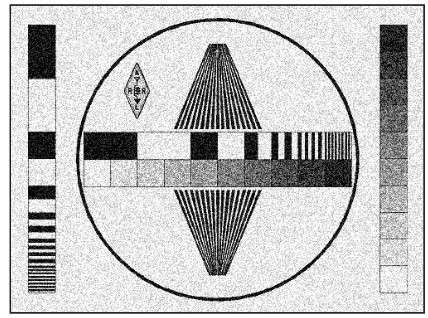
A snow-free, or "P5," picture rating (see **Fig 8**) requires at least 200 μV (–61 dBm) of signal at the input of the analog AM ATV receiver, depending on the system noise figure and bandwidth. The noise floor increases with bandwidth. Once the receiver system gain and noise figure reaches this floor, no additional gain will increase sensitivity. At 3-MHz bandwidth the noise floor is 0.8 μV (–109 dBm) at standard temperature in a perfect receiver. Analog TV luminance bandwidth starts rolling off around 3 MHz to separate it from the color subcarrier at 3.58 MHz. If you compare this 3 MHz bandwidth to an FM voice receiver with 15 kHz bandwidth, there is a 23 dB difference in the noise floor.

Much like the ear of an experienced SSB or CW operator, however, the eye can pick out sync bars in the noise below the noise floor. Sync lock and large, well contrasted objects or lettering can be seen between 1 and 2 μV with AM ATV. Color and subcarrier sound come out of the noise between 2 and 8 μV depending on their injection level at the transmitter and characteristics of your TV set. For the ATV DXer, using an older analog TV that does not go to blue screen or go blank (like a video squelch) with weak signals is a must, especially when rotating the antenna for best signal.

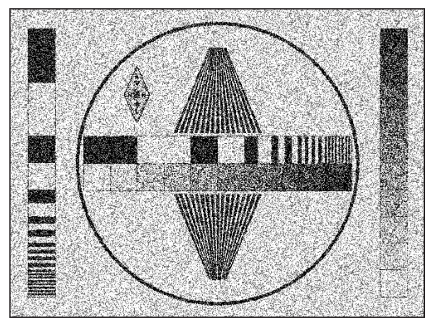
Operators must take turns transmitting on the few available channels. Two meter FM is used to coordinate ATV contacts, and the 2 meter link allows full-duplex audio communication between many receiving stations and the ATV transmitting station speaking on the sound subcarrier. This is great for interactive show and tell. It is also much easier to monitor a squelched 2 meter channel using an omnidirectional antenna rather than searching out each station by rotating a beam. Depending on the third-harmonic relationship to the video on 70 cm, 144.34 MHz and 146.43 MHz (simplex) are the most popular frequencies. The 2 meter audio is often mixed with the subcarrier sound on ATV repeater outputs so all can hear the talkback.



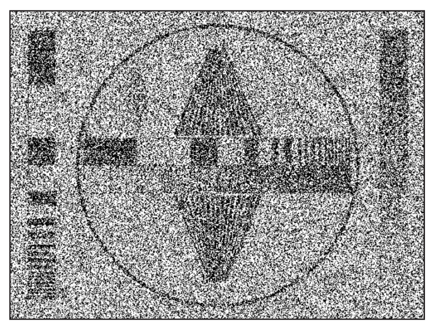
P5 — Excellent



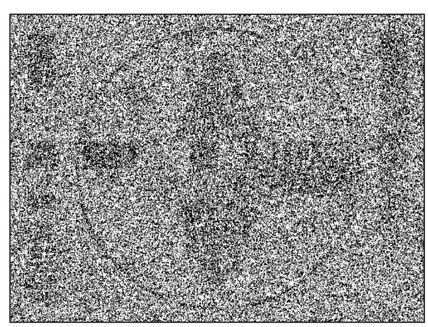
P4 — Good



P3 — Fair



P2 — Poor



P1 — Barely perceptible

Fig 8 — An ATV quality reporting system.

2 Amateur TV Systems

Regardless of the type of ATV you're interested in — analog AM, FM or digital — you'll need to assemble the appropriate receiving and transmitting equipment and find other stations to work. A basic AM 70 cm ATV station is shown in **Fig 9**. Very few multimode transmitters and transceivers support the broadband ATV mode and therefore most use equipment specifically designed for ATV. Sending video is easy by plugging in to the ATV transmitter your camcorder, video camera, digital camera, VCR, or any device with standard video output (usually RS-170) that can be viewed on an analog video monitor, VCR or a TV set's video input.

2.1 Analog AM ATV

Fig 10 shows the makeup of an analog AM TV channel (also called an NTSC channel) used for ATV, cable TV and for broadcast TV before the switch to digital. The channel is 6 MHz wide to accommodate the composite video, 3.58 MHz color subcarrier and 4.5 MHz sound subcarrier. Given the NTSC 525 horizontal line and 30 frames per second scan rates, the resulting horizontal resolution bandwidth is 80 lines per MHz. Therefore, with the typical TV set's 3 dB rolloff at 3 MHz (primarily in the IF filter) in older TVs, up to 240 vertical black lines can be seen. Newer TVs have better filters resulting in higher resolutions. Color bandwidth in a TV set is less than this, resulting in up to 100 color lines. Lines of resolution are often confused with the number of horizontal scan lines per frame. The video quality should be every bit as good as on a home video recorder. DXers, however, may add a 1 MHz or less band-pass filter between the downconverter and TV input on channel 3 to reduce the noise floor to dig out sync bars or black call letters.

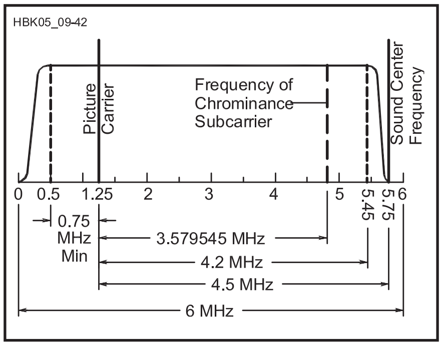


Fig 10 — An analog VSB NTSC 6 MHz video channel with the video carrier 1.25 MHz up from the lower edge. The color subcarrier is at 3.58 MHz and the sound subcarrier at 4.5 MHz above the video carrier.

Most ATV is analog AM double sideband (DSB), with the widest component being the sound subcarrier out ±4.5 MHz. As can be seen in **Fig 11**, the video power density is down more than 30 dB at frequencies greater than 1 MHz from the carrier — more than 90% of the spectrum power is in the first 1 MHz on both sides of the carrier.

To fit within a 6 MHz wide channel, NTSC broadcast stations used an approach called vestigial sideband (VSB). VSB involves sup-

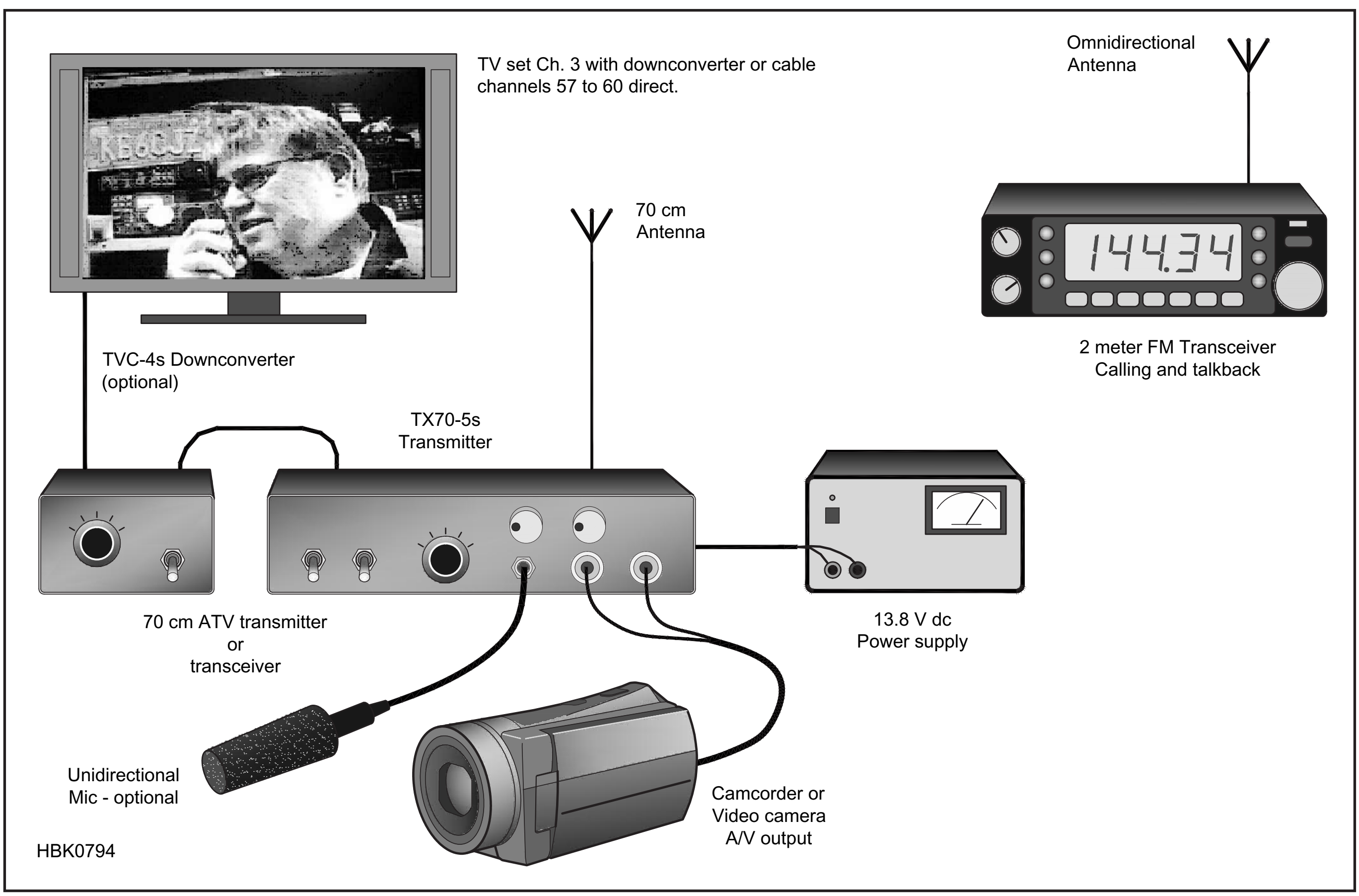


Fig 9 — Block diagram of a basic 70 cm AM ATV station with an optional downconverter. A TV set can be used without a downconverter, but it's better to have one for weak signal DX and if the video carrier frequency is more than 1 MHz from the cable channel frequency. If receiving an AM or DTV crossband repeater output on 33 or 23 cm, the downconverter would be connected to its own antenna and not through the TR relay in the transmitter. This makes it possible to see your own video coming back.

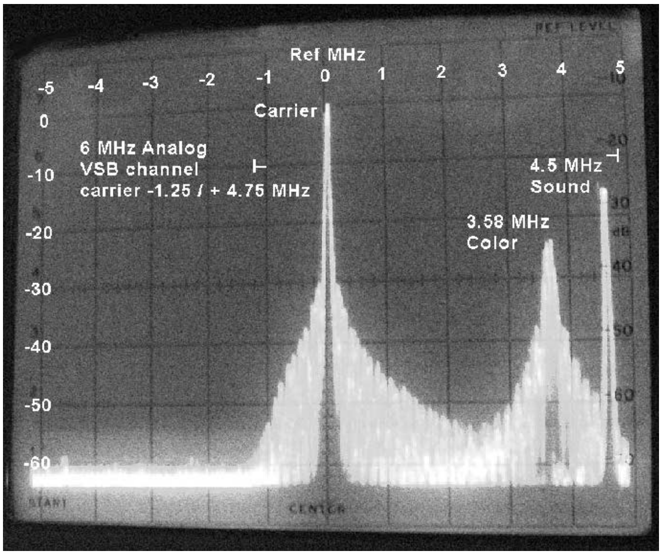


Fig 11 — Spectral display of a color analog AM VSB ATV signal. Spectrum power density varies with picture content, but typically 90% of the sideband power is within the first 1 MHz.

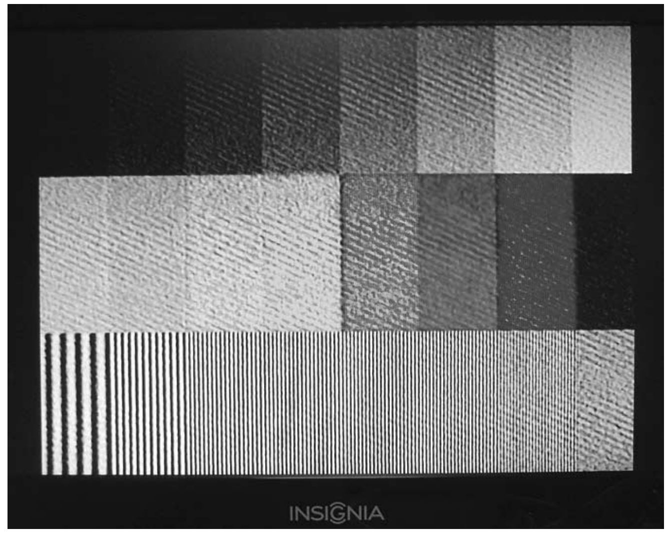


Fig 12 — AM ATV interference susceptibility. Notice the cross-hatch lines from an interfering –100 dBm carrier 1 MHz above the –60 dBm video carrier frequency into the TV receiver.

pression, but not elimination, of the lower sideband so that it occupies less than 1 MHz. In addition, instead of combining a 4.5 MHz subcarrier to produce sound, broadcast stations used a second sound transmitter offset above the video carrier by 4.5 MHz so that the sound signal does not appear in the lower sideband.

DSB and VSB are both compatible with analog cable TV tuners, but the lower sound and color subcarriers are rejected in the TV set IF filter as unnecessary. In the case of VSB, less than 5% of the lower sideband energy is attenuated. The other significant energy frequencies are the sound (set in the ATV transmitter at 15 dB below the peak sync) and the color at 3.58 MHz (greater than 22 dB down).

AM ATV FREQUENCIES

The lowest frequency amateur band wide enough to support an analog AM ATV channel is 70 cm (420-450 MHz), and it is the most popular. With transmit power, antenna gains and feed line losses equal, decreasing frequency increases communication range. The 33 cm (902-928 MHz) band generally covers half the distance that 70 cm does, but this can be made up to some extent with high-gain antennas, which are physically smaller at the higher frequency. Depending on local band plan options, there is room for no more than two simultaneous AM ATV channels in the 33 cm and 70 cm bands without potential interference. Similar to over-the-air broadcast TV, adjacent channels are skipped to avoid interference from a stronger station immediately adjacent to a weaker one. Cable channels don't have that problem because they equalize the amplitude of all the channels. If there is an in-band ATV repeater, simplex ATV operation shares space with the repeater input. Before transmitting, check with local ATV operators, repeater owners and frequency coordinators listed in the *ARRL Repeater Directory* for the coordinated frequencies used in your area.

The most popular in-band repeater output frequency is 421.25 MHz and is the same as cable channel 57. At least 12 MHz of separation is necessary for in-band repeaters because of TV-set adjacent-channel rejection and VSB filter characteristics. Cross-band ATV repeaters free up a channel on 70 cm for simplex and make it easier for repeater users to monitor their own repeated video with only proper antenna separation needed to prevent receiver desensitization.

Simplex, public service and R/C models use 426.25 MHz in areas with cross-band repeaters, or as an alternative to the main ATV activities on 434.0 or 439.25 MHz. The spectrum power density is so low at frequencies greater than 1 MHz from the video carrier of an AM analog ATV transmission that interference potential to other modes is low.

On the other hand, interference potential *to* ATV *from* other modes is high. Because a TV set receives a 6-MHz bandwidth, analog AM ATV is more susceptible to interference from many other sources than are narrower bandwidth modes. Interference 40 dB below the desired signal can be seen in the video in **Fig 12**. Many of our UHF (and higher) amateur bands are shared with radar and other government radio positioning services. Signals from these services show up as horizontal bars in the picture. Interference from amateurs who are unaware of the presence of the ATV signal (or in the absence of a technically sound and publicized local band plan) can wipe out the sound or color, or can create diagonal lines in the picture.

Other stations operating on narrowband modes more than 1 MHz above or below the video carrier rarely experience interference from an AM ATV signal, or even know that the ATV transmitter is on the air, unless the narrowband station is operating on one of the subcarrier frequencies or the stations are too near one another.

If the band is full and the lower sideband color and sound subcarrier frequencies need to be used by a dedicated link or repeater, a VSB filter in the antenna line can attenuate them another 20 to 30 dB, or the opposite antenna polarization can be used for more efficient packing of the spectrum.

Since most amateur linear amplifiers reinsert the lower sideband to within 10-20 dB of DSB, a VSB filter in the antenna line is a sure and cost-effective way to reduce the unnecessary lower sideband subcarrier energy if more than 1 W is used. VSB cable modulators can also be used if strict attention is made to keep the drive level in the proper range of highly linear amplifiers. In the more populated areas, 2 meter calling or coordination frequencies are often used to work out operating time shifts or other techniques to accommodate all users sharing or overlapping the same segment of the band.

RECEIVING AM ATV

Since the 70 cm band corresponds to cable TV channels 57 through 61, seeing your first ATV picture may be as simple as connecting

a good outside 70 cm antenna (aligned for the customary local polarization) to a cable-ready TV set's antenna input jack. Your broadcast TV antenna, twin-lead or RG-6 coax may not be good enough for receiving the much lower power ATV transmissions. Cable channel 57 is 421.25 MHz, and each channel is progressively 6 MHz higher. (Note that analog cable channels and the old NTSC broadcast UHF channel frequencies are different above channel 13.) Check the *ARRL Repeater Directory* for a local ATV repeater output that falls on one of these cable channels. Cable-ready TVs may not be as sensitive as a low-noise downconverter designed just for ATV, but this low cost technique is well worth a try.

Most stations use a variable tuned or crystal referenced downconverter specifically designed to convert the whole amateur band down to a VHF TV channel. Generally the 420 and 902 MHz bands are converted to TV channel 3 or 4, whichever is not used for over-the-air broadcast TV in the area. For 1240 MHz converters, channels 7 through 10 are used to get more image rejection.

The downconverter consists of a low-noise preamp, mixer and tunable or crystal-referenced local oscillator. Any RF at the input comes out at the lower frequencies. All signal processing of the AM video and FM sound is done in the TV set. A complete receiver with video and audio output would require all of the TV set's circuitry except the sweep and video display components. There is no picture quality gain by going directly from a receiver to a video monitor (as compared with a TV set) because IF and detector bandwidth are still the limiting factors. The Automatic Frequency Control (AFC) in a TV will normally lock on to a video carrier over a little more than ±1 MHz, so frequency drift and accuracy are not nearly as significant as experienced with voice modes. For instance, a TV set to cable channel 59 (433.25 MHz) will normally lock on to a 434.0 MHz ATV signal.

A good low-noise amateur downconverter with 15 dB gain ahead of a TV set will give sensitivity close to the noise floor. A preamp located in the shack may not significantly increase sensitivity, but rather can reduce dynamic range and increase the probability of intermodulation interference. Sensitivity can best be increased by reducing feed line loss or increasing antenna gain. Or you can add an antenna-mounted preamp, which will eliminate the effects of loss in the feed line and loss through TR relays in the transmit linear amplifier. Each 6 dB total improvement — usually a combination of increased transmitter power, antenna gain or receiver sensitivity and reduced feed line loss — can double the line-of-sight distance or improve quality by 1 P unit (a measure of picture quality).

DRIVING AMPLIFIERS WITH AM ATV

Linear amplifiers for use with wideband AM video require some special design considerations compared to amplifiers used for FM and SSB voice operation. Many high-power amateur amplifiers would oscillate (and possibly self destruct) from high gain at low frequencies if feedback networks and power RF chokes did not protect them. These same stability techniques can affect operation over a 5-MHz video bandwidth. Sync, color and sound can be distorted unless the amplifier has been carefully designed for both stability and AM video modulation.

Several manufacturers offer special ATV amplifiers or standard models designed for all modes, including ATV. The collector and base bias supplies have a range of capacitors to keep the voltage constant under video modulation, while at the same time using the minimum-value low-resistance series inductors or chokes to prevent self-oscillation.

Almost all amateur linear power amplifiers exhibit some degree of gain compression from half-power to their full rated PEP output. For proper AM ATV operation, the amplifier can be driven to PEP output power of no more than its 1 dB gain compression level. If more power is needed, the analog AM ATV exciter/modulator can use a sync stretcher to maintain the proper transmitted video-to-sync ratio to compensate for higher outputs (see **Fig 13**).

To adjust a station with an ATV amplifier, disconnect the video source and set the pedestal control in the ATV transmitter's modulator for maximum power output. Then set the transmitter's RF power control to drive the amplifier to 90% of rated PEP output (this is the peak sync level). The 90% level is necessary to give some headroom for the 4.5 MHz sound subcarrier that is mixed and added with the video waveform. Once this peak sync level is set, use the blanking pedestal control to reduce amplifier output to 60% of this level. For example, a 100-W amplifier would first be set for 90 W with the RF power control and then 54 W with the pedestal control. Then the video can be plugged back in and the video gain adjusted for best picture.

If you could measure RF output with a peak-reading power meter made for video, the power would be between 90 and 100 W PEP. A dc-coupled oscilloscope connected to an RF diode detector in the antenna line shows that the sync and blanking pedestal power levels remain constant at their set levels regardless of video gain setting or average picture contrast. On an averaging power meter, however, it is normal with video to read about half the amplifier's rated power. The power reading will actually decrease with increasing video gain or with a change to a predominantly white picture. An averaging RF power meter cannot give an accurate measurement for an AM video signal given so many variables. If the amplifier drive level is properly set up according to the procedure outlined above, the actual sync tip PEP will remain constant.

Analog cable TV modulators can also be used to drive linear amplifiers, but most do not have adjustable sync stretchers. When driving an amplifier, the level must be kept below the upper nonlinear gain curve of the amp's output curve in order to maintain the proper video to sync ratio. The same is required when driving an amp from any low power ATV transmitter that does not have adjustable sync stretching. Most amateur amplifiers can be driven to their 1 dB gain compression output levels for ATV, which typically occurs around half the rated PEP output.

2.2 Frequency Modulated ATV

In Europe, FM ATV on the 23 cm (1240 MHz) band is the standard because there is little room for ATV in the amateur 70 cm band. In the US, AM on 70 cm remains the most popular ATV mode because of equipment availability, lower cost, less occupied bandwidth and use of a standard analog TV set for receiving. However, FM ATV on the

Fig 13 — An oscilloscope used to observe a video waveform. The lower trace is the video signal as it comes out of the sync stretcher. The upper trace is the detected RF signal from the amplifier.

higher bands is gaining interest among experimenters and repeater owners for links and alternate inputs.

As shown in **Fig 14**, FM ATV occupies 17 to 21 MHz depending on deviation and sound subcarrier frequency. While the 70 cm band is 30 MHz wide and thus theoretically could accommodate a 20 MHz wide FM ATV signal, the great interference potential to other users of the band precludes its use there. Most available FM ATV equipment is made for the 0.9, 1.2, 2.4 and 10.25 GHz bands. The 3.3 and 5.6 GHz amateur bands are also being explored by using C-band satellite receivers and converted Part 15 equipment.

The US standard for FM ATV is 4 MHz deviation with the 5.5-MHz sound subcarrier set to 15 dB below the video level. Suggested frequencies are 1252 or 1255 MHz to stay away from FM voice repeaters and other users higher in the band, while keeping sidebands above the 1240 MHz band edge. Using the US standard, with Carson's rule for FM occupied bandwidth (see the **Modulation** chapter), the bandwidth is calculated as just under 20 MHz — so 1250 MHz would be the lowest possible frequency. Check with local frequency coordinators before transmitting because the band plan permits links and other modes in that segment that may not be published.

C-band satellite TV receivers directly tune anywhere from 900 to 2150 MHz and may need a preamp added at the antenna for use on the 33 cm and 23 cm amateur bands. Early satellite TV receivers were made for antenna mounted LNBs (low noise block converters) with 40 dB or more gain. Satellite receivers are made for wider deviation (11 MHz) and need some video gain to give the standard 1 V P-P video output when receiving a signal with standard 4 MHz deviation. The additional video gain can often be had by adjusting an internal control or changing the gain with a resistor.

Some of the inexpensive Part 15 wireless video receivers in the 33 cm band use 4 MHz deviation FM video. Most of the 2.4-GHz Part 15 units are FM, so they can be used directly. On 2.4 GHz, some of the Part 15 frequencies are outside the ham band and care should be taken to use only those frequencies at least 8 MHz inside the 2390-2450 MHz ham band.

Part 15 receivers may or may not have the standard de-emphasis video network, however, so some circuitry may have to be added. Video pre-emphasis in the transmitter and de-emphasis in the receiver can double the communication distance or give 6 dB of SNR improvement by reducing the receiver noise bandwidth. Coordination among local stations is needed, though, because you cannot match stations that have the networks with those that don't without distorting the video greatly.

2.3 Digital ATV

The greatest advantage to running digital ATV is that you have a perfect P5 picture all the way down to 15 dB (with 8-VSB) above the noise floor, and higher definition or more than one picture are possible in the same 6 MHz channel width used for analog AM ATV (see **Fig 15**). If you use the signal-to-noise level required to have snow-free ATV as a reference, 8-VSB DTV is 20 dB better than the 4 MHz deviation FM ATV and 32 dB better than analog AM ATV. This is a significant consideration for long-distance, point-to-point, line-of-sight paths and for paths requiring wide fade margins. Tuning in DTV requires greater accuracy and takes more patience if using a tunable downconverter. QAM, for instance, at cable channel 58 on one TV needed to be tuned within 400 kHz but took a second or two within that range for the picture to appear. 64-QAM is much more resistant to interference than AM and stays P5 up to almost equal amplitude with another carrier.

DTV can send much more usable picture and sound information in the same bandwidth as analog AM ATV under the theory that you don't have to send a continuous serial stream of a scanned picture at 30 interlaced frames per second. Rather, in DTV you transmit one whole frame and then send frames of only the changed pixels (or those pixels predicted to change, as explained in the next paragraph). Just the changes are sent a specified number of times (usually up to 15 times) before starting over again with a new complete frame.

There are complex algorithms based on how the human eye and mind perceive the picture as well as data compression techniques. For instance, there is the probability that a pixel or group of pixels that are moving in a direction on the screen will occupy the adjacent pixel location at a certain time. According to Henry Ruh, AA9XW (a long-time ATVer and Chief Engineer at WYIN-TV in Chicago), the coder/decoder (codec) software may expect a moving pool ball to continue in a straight line. If you watch closely, however, you may see the ball go deeper into the cushion than it really did until the next full frame. The bottom line is that the picture you see may be 10% actual data and 90% predictions.

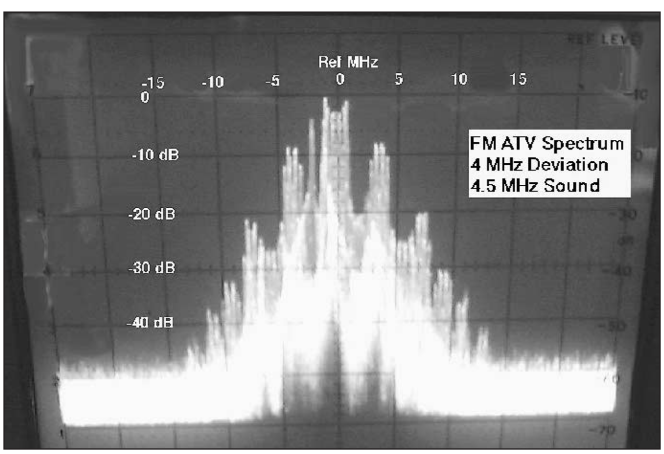


Fig 14 — Spectral display of an FM ATV transmission using 4 MHz deviation with a 4.5 MHz sound subcarrier. (Note that 5.5 MHz is the standard and would be 2 MHz wider.) Occupied bandwidth as defined in FCC Rule 97.3(a)(8) is –26 dB down from the mean power points.

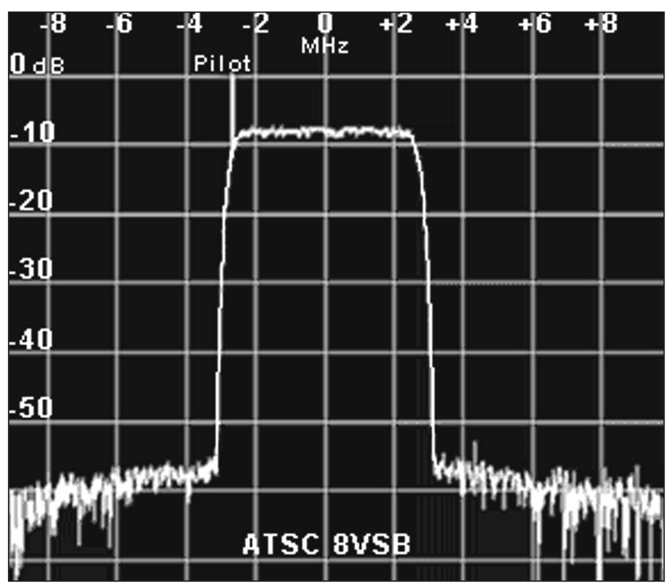


Fig 15 — Spectral display of an ATSC 8-VSB digital TV transmission. Note the pilot carrier unique to this mode of DTV.

DIGITAL ATV TRANSMITTER REQUIREMENTS

As can be seen in **Fig 15**, in an 8-VSB signal there is a pilot carrier 310 kHz up from the lower channel edge generated by a dc offset of the eight level modulation. The pilot carrier has a tight tolerance of 3 Hz and gives the RF PLL circuits in the 8-VSB receivers something to lock onto that is independent of the data being transmitted. Unlike 8-VSB, DVB-T, DVB-S or D-CATV do not have a pilot carrier (see **Figs 16** and **17**).

DTV transmissions are rated at average power. With 8-VSB modulation, the peak power is 7 dB greater than the average, or about 5 times. DTV transmission requires an amplifier with high linearity and good IMD performance to prevent distortion, noise and spectrum sideband growth. Amateur amplifiers with transistors used for AM, SSB or FM are not linear enough. Newer amplifier designs and "brick" amplifiers using MOSFET or LDMOS devices are the current choice of D-ATV experimenters. For proper operation, amplifiers for 8-VSB operation are run at average powers 20% of their rated 1 dB gain compression levels. For example, an amplifier you might run at 100 W PEP output with analog AM ATV would run at 20 W average power or less for 8-VSB DTV. With D-CATV, DVB-T and DVB-S, power output can run slightly higher — up to 33% of an amplifier's rated 1 dB gain-compression level. As described earlier, DTV requires less signal strength than analog AM ATV to produce a P5 picture. Lower transmit power levels may not be an issue if the signal strength into the TV receiver is above the cliff level.

With DTV, it's not good amateur practice to follow the ham tradition on other modes of increasing amplifier drive to the point that a receiver starts to break up and then back the drive down a little. Although increased transmitter IMD may not affect the received signal until the combination of the received signal-to-noise and the added transmitter amplifier noise reaches the cliff and the picture goes away, the generated sideband levels can

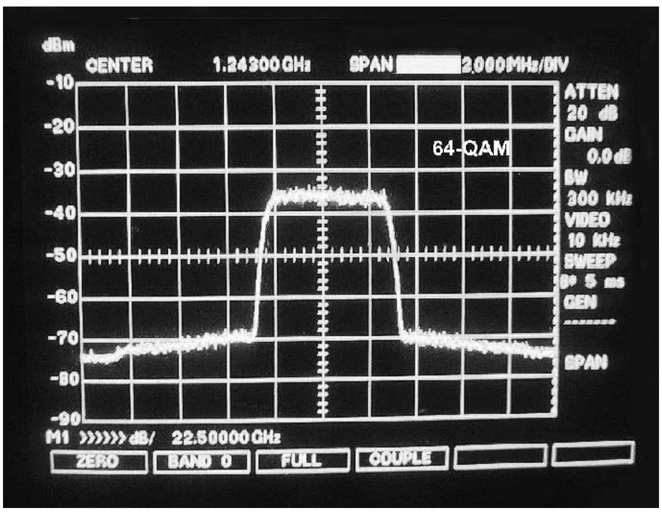


Fig 16 — "Haystack" spectral display of a 64-QAM digital TV transmission.

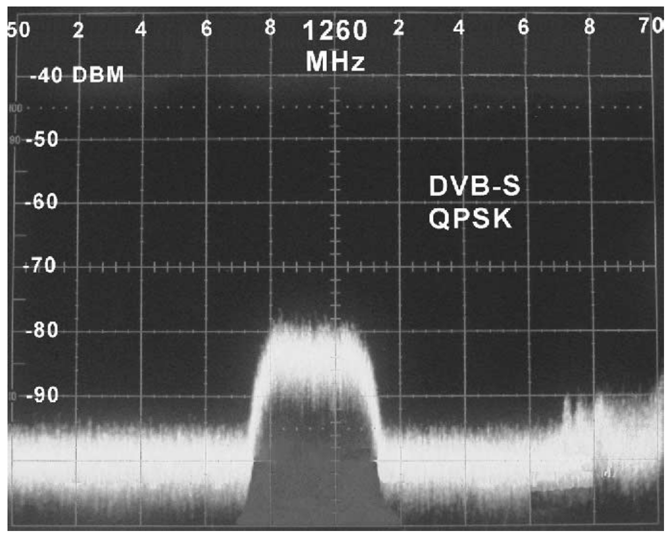


Fig 17 — A DVB-S QPSK signal from the WR8ATV repeater output as received on a spectrum analyzer. Note that the average power appears to be not too far above the noise floor, but gives a P5 picture. P units are measures of picture quality from P1 to P5 with P5 being the clearest and best picture.

Fig 18 — Mobile ATV as shown here with a portable TV works fine using D-CATV 64-QAM, but it exhibits occasional freeze or tile effect from drop outs and multipath.

Fig 19 — Art Towslee, WA8RMC, in his shack transmitting QPSK DTV through the local ATV repeater in Columbus, Ohio.

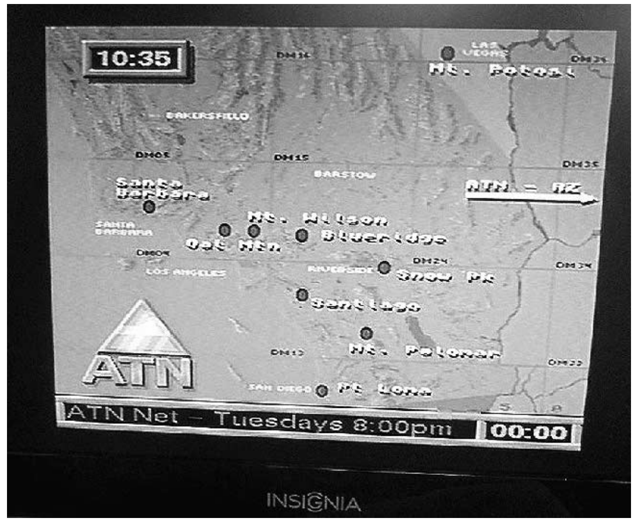


Fig 20 — The ID of the W6ATN repeater output using D-CATV 64-QAM on 1243 MHz is shown at A. The Amateur Television Network has many linked AM and FM ATV repeaters — see www.atn-tv.org. At B, the Hides UT-100 USB DVB-T Modulator/Demodulator (www.hides.com.tw) will transmit and receive over a programmable range of 50 to 950 MHz in 1 kHz steps. The nominal 1 mW output power is adjustable over a 30 dB range for amplifier drive set up. The device is plugged into a USB port on a *Windows* computer, and the computer is used for the video coding and decoding the MPEG video. This module is under $250.

be quite large and interfere with other users on adjacent frequencies.

An analog VSB filter in the antenna line can help keep the unwanted sideband growth down. As can be seen in Figs 15, 16 and 17, DTV spectrum power density is high across the whole channel width and will show up as noise in a narrowband receiver tuned within the 6 MHz channel. For this reason, DTV should be used in the higher bands or 420-431 MHz segment of the 70 cm band so as not to interfere with FM voice repeaters, weak signal modes and satellite work.

DTV ISSUES

DTV using 8-VSB will stop working or freeze-frame with just a few miles per hour of antenna movement or multipath ghosting. Unlike analog ATV, 8-VSB DTV is impractical for mobile, portable, R/C vehicles and balloons. Developments in technology may allow mobile reception of over-the-air 8-VSB broadcast in the future. DVB-S does not have this problem, but popularity may depend on the availability of inexpensive "free to air" satellite receivers in the USA. DVB-S and D-CATV has some multipath susceptibility, but tests in Europe and the US (as in **Fig 18**) show that they perform well under mobile conditions. Over time, 64-QAM D-CATV or QPSK DVB-S will likely become the most widely adopted amateur DTV system in the US depending on equipment cost and availability. Some computer-based systems may be developed also.

Another unique factor with DTV communication is getting used to the digital processing delay when using a 2 meter talkback channel or even duplex audio and video. The time delay can vary from a few hundred milliseconds to a few seconds.

AMATEUR DTV SYSTEMS

The first amateur DTV repeater in the US is in Columbus, Ohio (see **www.atco.tv**). This repeater uses a cable modulator with QPSK modulation on 1260 MHz. Art Towslee, WA8RMC (shown in **Fig 19**) has a good simplified explanation of the various DTV modes on the ATCO club web site menu.

The W6ATN repeater on Mt. Wilson, 5000 feet above the Los Angeles basin, is the first ATV repeater to have a D-CATV 64-QAM output as shown in **Fig 20**.

Nick Sayer, N6QQQ, has a blog in which he describes his experiments with 8-VSB on 33 cm — **nsayer.blogspot.com/search/label/ham**.

Early work by Uwe Kraus, DJ8DW and others is described at **www.von-info.ch/hb9afo/histoire/news043.htm**. Their experiments date to 1998, when they were the first to transmit moving color pictures with sound via a digital amateur television link over a distance of 62 miles. The early work used a 2 MHz bandwidth on 70 cm with 15 W output and 15 dB gain antennas.

Also see **www.von-info.ch/hb9afo/datv_e.htm** for sources and descriptions of DTV encoder and exciter boards. Most of these will take in a video signal and two audio signals and output a few milliwatts on an IF frequency to be mixed up to a ham band. The signal may also have a specific ham band output. Some have jumpers to select QPSK, GMSK, QAM or 8-VSB modulation as well as various forward error correction (FEC) and symbol rates.

With the shift to broadcast DTV in the US, it's possible that consumer and cable head-end RF modulators will start appearing for connecting video devices to TVs and adding DTV to cable systems. This will bring the size and cost of chip sets down and make experimentation with 8-VSB and other DTV modes more economically practical for amateurs. For example, the UT-100 USB DVB-T Modulator/Demodulator by Hides just became available (**www.hides.com.tw**). Similar devices being planned will include 64-QAM in addition to the DVB-T module currently available for $200/$240 — a significant price decrease. This USB DVB-T transmitter/receiver however does have to be used with a computer for the MPEG compression codec. A standalone transmitter should be available in late 2013. For more technical information on MPEG-2 compression see **en.wikipedia.org/wiki/MPEG-2**.

2.4 ATV Antennas

Foliage greatly attenuates signals at UHF, so place antennas above the treetops for the best results. Beams made for 432 MHz SSB/CW work or 440 MHz FM may not have enough SWR bandwidth to cover all the ATV frequencies for transmitting, but they are okay for reception. A number of manufacturers make beam antennas designed for ATV use that cover the whole band from 420 to 450 MHz. Use low-loss feed line and weatherproof all outside connectors with tape or coax sealer. Almost all ATV antennas use N connectors, which are more resistant to moisture contamination than other types. See the **Transmission Lines** and **Component Data and References** chapters for information on appropriate cable and connectors.

Antenna polarization conventions vary from area to area. It is common to find that the polarization was determined by the first local ATV operators based on antennas they had in place for other modes. Generally, UHF/microwave operators active on SSB, CW and digital modes have horizontally polarized antennas, while those into FM, public service or repeaters have vertical antennas. Check with local ATV operators before permanently locking down your antenna mounting clamps. Circularly polarized antennas let you work all modes, including satellites.

2.5 ATV Identification

ATV identification can be on video or the

sound subcarrier. A large high-contrast call sign on the wall behind the operating table in view of the camera is the easiest way to fulfill the requirement (see **Fig 21A**). Transmitting stations fishing for DX during band openings often make up call sign IDs using fat black letters on a white background to show up best in the snow. Their city and 2 meter monitoring frequency (typically 144.34 or 146.43 MHz) are included at the bottom of the image to make beam alignment and contact confirmation easier.

Quite often the transmission time exceeds 10 minutes, especially when transmitting demonstrations, public service events, balloon flights or from videotape. Intuitive Circuits makes a variety of boards that will overlay text on any video looped through them. Call sign characters and other information can be programmed into the board's nonvolatile memory by on-board push buttons or via an RS-232 interface from a computer (depending on the version and model of the board). See Fig 21B. One model will accept NMEA-0183 standard data from a GPS receiver and overlay latitude, longitude, altitude, direction and speed, as well as call letters, on the applied camera video. This is ideal for ATV rockets, balloons and R/C vehicles. The overlaid ID can be selected to be on, off or flashed on for a few seconds every 10 minutes to automatically satisfy the FCC ID requirement. The PC Electronics VOR-3 video operated relay board has an automatic nine-minute timer, and it also has an end-of-transmission timer that switches to another video source for ID.

2.6 ATV Repeaters

There are two kinds of ATV repeaters: in-band and cross-band. In-band repeaters for 70 cm are more difficult to build and use, yet they are more popular because equipment for that band is more available and less expensive. Many ATV repeaters have added streaming video of their outputs to the Internet so users can see when they are active. Some repeaters even use the Internet to establish links. A good number of US repeaters can be found on the **www.batc.tv** Streaming Members website.

(A)

(B)

Fig 21 — At A, the simplest video identifier is to draw your call sign on a piece of paper and put it on the wall of your ham shack and in view of the camera. Doug Moon, K6KMN, also has his old auto call letter license plate as his ID. At B, the call sign, event name and location are overlaid on the video. During a public service event such as a long trail running race it is easy to forget to ID especially if operating full duplex and a lot is going on. See www.foothillflyers.org/hamtvac100.html for a description of ATV at the Angeles Crest 100 Mile Trail Race.

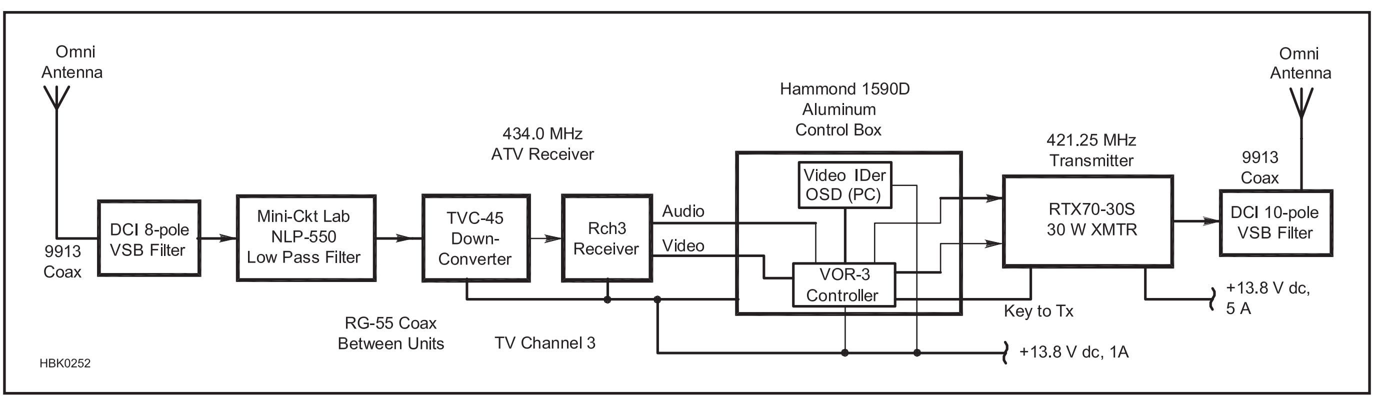


Fig 22 — A block diagram of a 70 cm in-band ATV repeater. The omnidirectional antennas are vertical and require 20 feet (minimum) of vertical separation to get >50 dB isolation to prevent receiver desensitization. Horizontal omnidirectional antennas require much more separation. A low-pass filter on the receiver is also necessary because VSB or cavity type filters repeat a pass-band at odd harmonics and the third-harmonic energy from the transmitter may not be attenuated enough. PC Electronics makes the receiver, transmitter and VOR. Video ID can be done with a video overlay board like the Intuitive Circuits model OSD-ID+ — by itself or even overlaid on a tower cam. Alternatively, an Intuitive Circuits ATVC-4+ ATV repeater controller board can do all the control box functions as well as remotely select from up to four video sources.

Why are 70 cm ATV repeaters more difficult to build than voice repeaters? The wide bandwidth of ATV makes for special filter requirements. Response across the 6-MHz passband must be as flat as possible with minimum insertion loss, but response must sharply roll off to reject other users as close as 12 MHz away. Special 6 to 10 pole inter-digital or comb-line VSB filters are used to meet the requirement. An ATV duplexer can be used to feed one broadband omnidirectional antenna, but an additional VSB filter is needed in the transmitter line for sufficient attenuation to keep noise and IMD product energy from desensitizing the receiver. The receiver and possibly the transmitter might also need a low-pass filter to attenuate the third harmonic which can pass through a VSB or band-pass filter with little attenuation and overload the receiver front end.

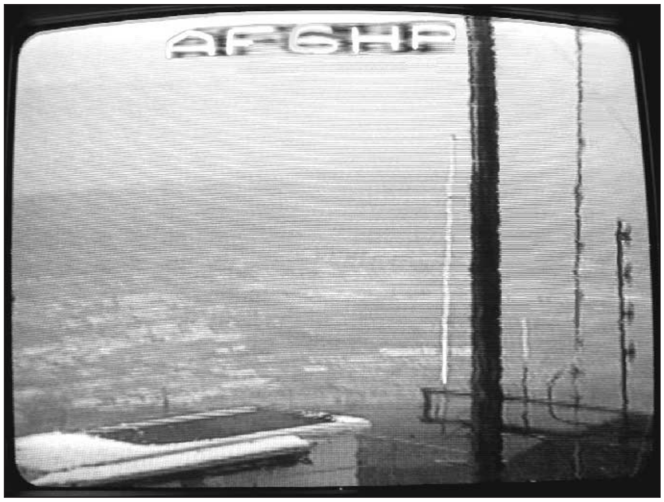


Fig 23 — ATV repeater "tower cam" IDs have become popular so that users can see approaching weather. Some cameras have remote pan and tilt, so users can observe ice build-up on antennas or activity at the repeater site.

A cross-band repeater requires less sophisticated filtering to isolate the transmitter and receiver because of the great frequency separation between the input and output. No duplexer is needed, only sufficient antenna spacing or low pass and/or high pass filters. In addition, a cross-band repeater makes it easier for users to see their own video. Repeater linking is easier too, if the repeater outputs alternate between the 23 cm and 33 cm bands.

A 70 CM ATV REPEATER

Fig 22 shows a block diagram for a simple 70 cm in-band analog AM ATV repeater. No duplexer is shown because the antenna separation (>50 dB) and VSB filters provide adequate isolation.

To prevent unwanted key up from other signal sources, ATV repeaters use a video operated relay (VOR). The VOR senses the horizontal sync at 15.734 kHz in much the same manner that FM repeaters use CTCSS tones. Just as in voice repeaters, an ID timer monitors VOR activity and starts the repeater video ID generator every nine minutes, or a few seconds after a user stops transmitting. A tower-mounted camera is often used in place of a video ID generator at repeaters (see **Fig 23**).

The repeater transmitter power supply should be separate from the supply for the rest of the equipment. With AM ATV the current varies greatly from maximum at the sync tip to minimum during white portions of the picture. Power supplies are not generally made to hold tight regulation with such great current changes at rates up to several megahertz. Even the power supply leads become significant inductors at video frequencies. They will develop a voltage across them that can be transferred to other modules on the same power supply line.

3 ATV Applications

3.1 Public Service

Live video from an incident site back to an Emergency Operations Center (EOC) is a valuable addition to disaster communications. A real-time view of the incident scene can give commanders an immediate feel for the overall picture of what is going on or zoom in on a critical component rather than rely solely on descriptions relayed by voice or data. ATV has the added benefit of full duplex audio. The ATV transmitting station in the field talks on the sound subcarrier and the EOC can talk back at the same time on 2 meter FM voice. Races, parades and other public service events benefit from a ham volunteer transmitting video back to medical and emergency response personnel of what is happening at a critical street corner or incident as shown in **Fig 24**. See how to put together a portable ATV transmitter in a belt pouch at **www.hamtv.com/atvpouch.html** and on page 9-11 of the 10th edition of the *ARRL Operating Manual* for radio amateurs. A camera and transmitter can be mounted on a robot and sent into a hazardous situation with no risk to people.

Fig 24 — A low power 50 mW battery operated portable 70 cm AM ATV transmitter is ideal for short range line of sight paths of up to 2 miles using 5 element beams. This setup can be used to show a critical intersection or condition of runners as an early warning to emergency response and aid station volunteers at races.

AN ATV "GO KIT"

Communications "Go-Kits" are popular with ARES and RACES groups. When an emergency occurs, hams can just grab their kit and go out in the field with everything they need. Nick Klos, AC6Y, put together three ATV Go-Kits for the police department ARES group in Corona, California. See **Fig 25**. Each kit uses an easy-to-transport Pack-N-Roll enclosure. (Pack-N-Rolls come in various sizes, have wheels, and have an extendable handle similar to airline carry-on luggage.) The ATV transmitter, 2 meter transceiver, battery and optional video monitor are fastened to plywood cut to fit the inside of the enclosure. A dc power supply can also be added if ac is available, or power can come from a dc extension cord with clips to connect to a car battery.

If the distance to be covered is short enough, a 2 meter/70 cm dual-band mobile vertical antenna connected through a duplexer and mounted on at least 10 ft of TV mast above the Go-Kit is sufficient for communication with a mobile command post. Longer or obstructed paths between the incident site and the EOC may require beams and more antenna placement care.

Multiple ATV Go-Kits allow for views of an incident site from different perspectives, including the police department helicopter and mobile or portable stations on the ground. The Go-Kits can also be used for parades, running and bike races, which are good operational practice for when the real emergency might happen.

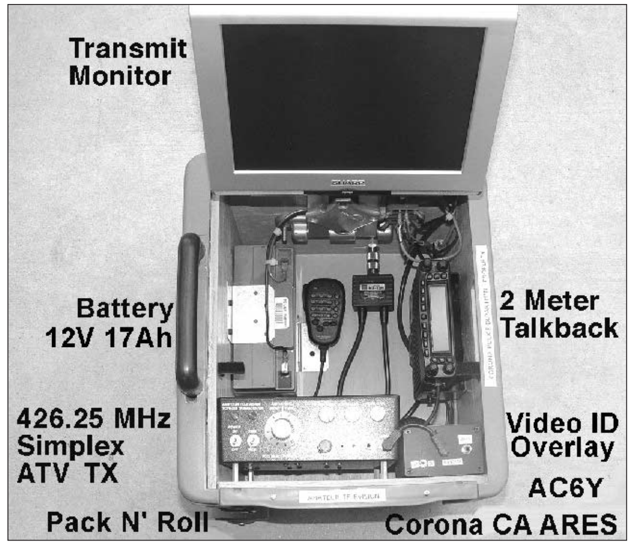


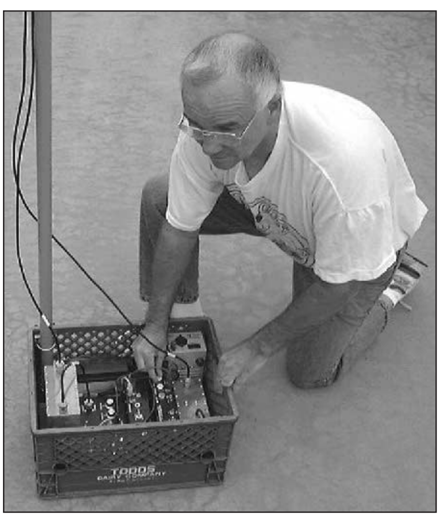
Fig 25 — This portable ATV Go-Kit for emergency and public service work was built by Nick Klos, AC6Y. It includes a 70 cm ATV transmitter, 2 meter FM transceiver and battery in a Pack N' Roll container.

PORTABLE REPEATERS

A portable ATV repeater for public service events can also be built in a Pack-N-Roll enclosure or a milk crate for easy transport and set up on the top of a building or hilltop by car or even helicopter. The path between an ATV station in the field and the EOC is rarely line-of-sight, so the portable ATV repeater can be placed at a high point that can be accessed from both locations.

The portable repeater shown in **Fig 26** is a cross-band unit with 70 cm input and 23 cm output. By using 70 cm input to the repeater, you get the best coverage for the lowest power by those moving around an incident site with hard-hat cameras or portable units. Another advantage to using low-in and high-out at the repeater is that filtering is much easier because you don't have to contend with strong repeater transmitter harmonics in the receiver. Antenna separation of 5 feet is usually enough running a low-power, low-in/high-out portable repeater.

With weaker signals, a low-pass filter in



(A)

(B)

(C)

Fig 26 — At A, Tom O'Hara, W6ORG, adjusts a portable ATV repeater for public service work that can be built in a milk crate. The block diagram is similar to Fig 14 but without the VSB filters. The transmitter is a PC Electronics RTX23-3 on 1253.25 MHz, the receiver is on 426.25 MHz, and small beams or omni antennas are used. For more details on construction, visit www.hamtv.com/info.html#portrpt. At B, the repeater is flown to a hilltop and quickly set up. Sharon Kelly, KF6OQO, is adjusting the antenna. At C, the video of a fire can be seen at an EOC on the other side of the hill while Gary Heston, W6KVC, talks back to the incident site ATV operator on 2 meters.

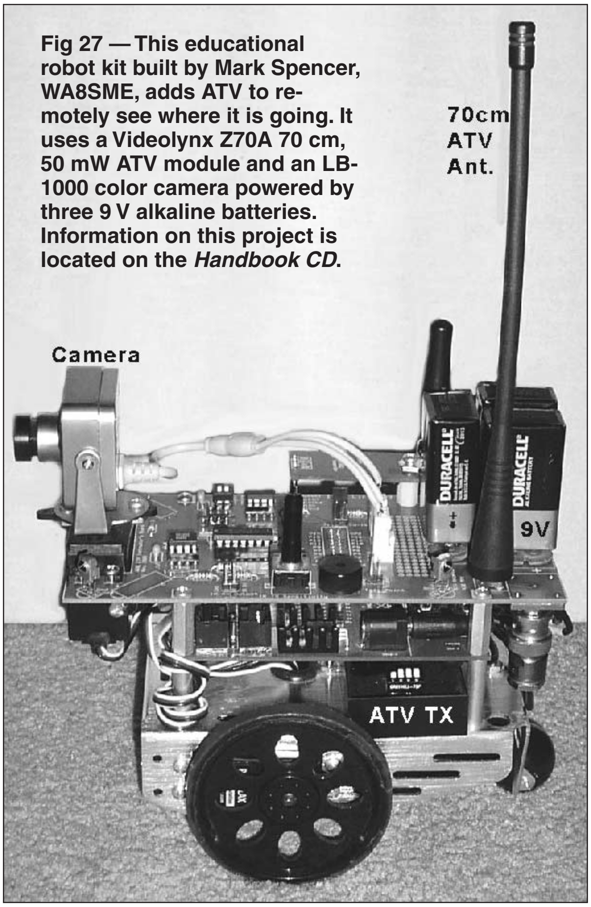


Fig 27 — This educational robot kit built by Mark Spencer, WA8SME, adds ATV to remotely see where it is going. It uses a Videolynx Z70A 70 cm, 50 mW ATV module and an LB-1000 color camera powered by three 9 V alkaline batteries. Information on this project is located on the *Handbook CD*.

the 70 cm receiver feed line and a high-pass filter in the 23 cm transmitter feed line may help to minimize desense. If a portable ATV repeater system is used at or near a communications site, band-pass filters in the antenna feed lines should be used to prevent intermodulation interference or receiver overload from nearby transmitters.

With compact 10 dBd gain corner reflectors or higher gain beams on 23 cm, you can cover more than 5 miles line-of-sight from the repeater to the EOC with just 3 W of transmitter power. The portable repeater shown is self-contained with a 12 V, 17 Ah battery that will last about 12 hours. Alternatives include ac-operated 13.8 V, 3 A power supply or a dc cord clipped to a car battery. A local camera can be plugged in and used if needed. Details of the portable repeater can be found at **www.hamtv.com/info.html** under Portable Public Service Repeater.

3.2 Radio Control Vehicles

Some hams also enjoy operating radio control (R/C) vehicles, and ATV can add a new dimension to that hobby. The size, weight and cost of color cameras have come way down, and ATV transmitters are smaller as well, so ATV stations can more easily be integrated into R/C vehicles to give them eyes and in some cases ears.

AN EDUCATIONAL TOOL

Mark Spencer, WA8SME (ARRL Amateur Radio Education and Technology Coordinator) added ATV capability to a Parallax Board of Education Robot (BOE/BOT) as shown in **Fig 27**. With the add-on ATV board, the BOE/BOT simulates a Mars Lander. The robot and ATV board are also used to teach students how a TV remote control works, as well as demonstrate remote sensing and data linking. This ATV application has encouraged students to use the kit as a science class project and become licensed hams in the process.

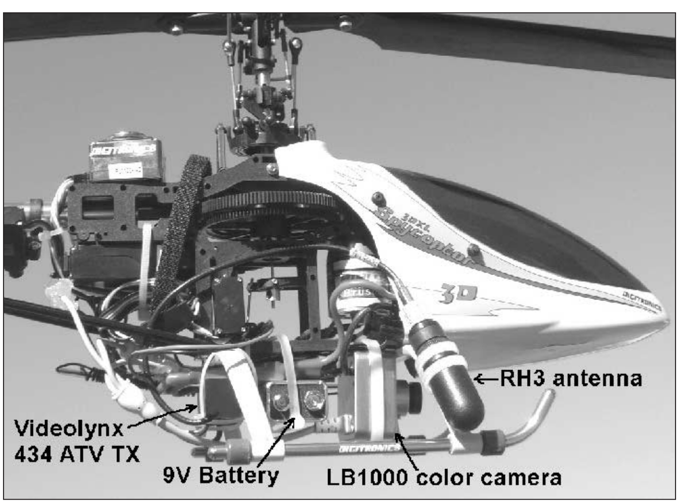
R/C VEHICLE TIPS

ATV and data transmitter modules have been put in R/C aircraft, blimps, cars and boats. A 50 mW transmitter on 70 cm is enough to give good video for ½ mile or so around an R/C flying field. An inverted ground-plane or vertical dipole is used typically on aircraft, but nulls in the radiation pattern can show up at steep bank angles. Ground-plane antennas are also used for receive because the pattern is broad. Mounting the receive antenna at least 10 feet above ground can help avoid multipath ghosting or signal blockage from nearby people and vehicles. Use of higher gain omnidirectional antennas is tempting for greater distance, but they have narrower radiation patterns and more nulls.

Operation at higher frequencies requires shorter antenna lengths that might better fit the physical size limitations of an R/C vehicle, but snow-free distance will be shorter given the same transmitter power and receive antenna gains.

If ac power is not available at the flying field for plugging in a TV, look for a portable television that can be powered from batteries. Some hams have used TV tuners designed for use with laptop computers. Position the

(A)



(B)

Fig 28 — At A, cable ties are used to fasten an LB-1000 color camera, Videolynx 434 ATV transmitter, 9 V battery and Diamond RH3 antenna to an R/C helicopter powered by an electric motor. At B, a computer with a TV tuner plugged into the USB port is used to view video coming from the ATV transmitter on the R/C helicopter — in this case, looking back at the R/C model operator.

screen to face north for the least sun washout. It is best for even experienced R/C operators to not fly solely by video, but to have a copilot observe directly as the camera's field of view is limited. (R/C organization safety rules require the aircraft to be in sight at all times.)

Typical 72 MHz or 50 MHz R/C receivers are not designed to operate with a transmitter in the same vehicle. The R/C receiver front end could overload from ATV transmitter RF, so control range testing is a must before the first flight. Testing can be done by having another ham (with a handheld radio for talkback) carry the R/C vehicle out to the normal limit of control distance. Then turn on the R/C transmitter and verify that the controls are working normally. Finally, turn on the ATV transmitter and again verify operation.

If the R/C receiver is captured by the ATV transmitter, then experiment with lowering power, changing antenna placement, or adding shielding or filtering. In the past, crystal oscillator leakage was often the culprit, rather than the 70 cm output, and could be cured by shielding. Interference may be less of a problem with a newer ATV transmitter that uses a PLL oscillator.

A PRACTICAL EXAMPLE

The added weight of the ATV system on the electric R/C helicopter shown in **Fig 28** is only 7 ounces, but first you need to determine that the craft can lift the added load. The extra equipment must be mounted to maintain balance around the aircraft's center of gravity. Some testing with equivalent weights first can save equipment from possible damage. Note the stubby flexible antenna mounted upside down on one of the skid supports. This is counterbalanced by mounting the R/C receiving antenna on the opposite side.

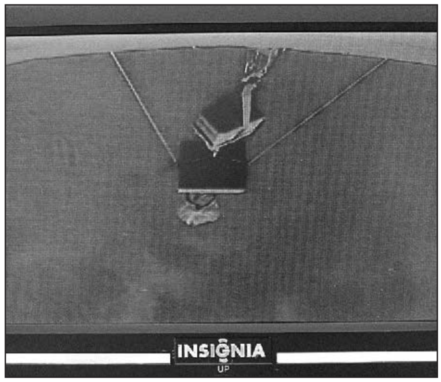
A separate battery should be used for the ATV system rather than tapping into the motor or R/C receiver battery. The voltage will vary during the flight and could add motor noise to the video. A standard 9 V alkaline battery will last for almost two hours of continuous duty with this system.

On larger R/C aircraft having sufficient payload, a GPS receiver and an Intuitive Circuits video overlay board can put the speed, altitude and direction, along with call sign, over the camera video.

3.3 ATV from Near Space

Seeing the ground fall away via ATV as an amateur rocket or balloon rises can be quite exciting as shown in **Fig 29**. There are a number of groups sending up balloons and rockets with instrumentation, beacons and repeaters in addition to ATV. Balloon transmissions have been received as far as 500 miles away as the instrument package rises to 100,000 ft

(A)



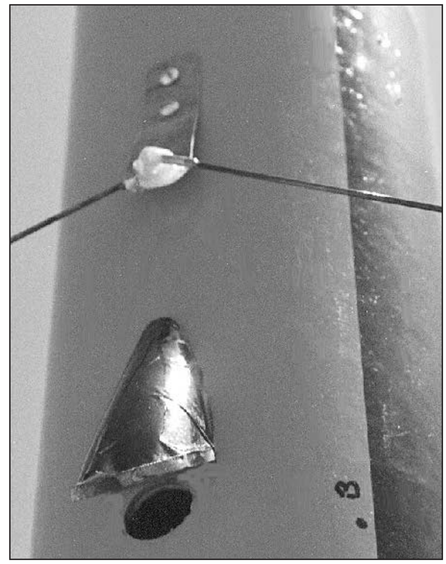
(B)

Fig 29 — At (A), an ATV camera view from a balloon at 93,399 feet shows the blackness of space, the curvature of the earth and hazy clouds below. Note that the standard NMEA altitude data output from GPS receivers is in meters. At (B), video received from a balloon on a 7 inch portable LCD TV at 20 miles slant distance. The camera is looking down at the instrument package, with clouds and the ocean below.

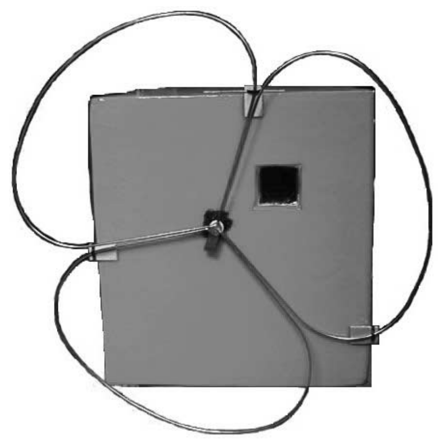
before the balloon pops from gas expansion and ultra violet decomposition and then parachutes back to earth. Radio direction finding clubs are often asked to help find where the balloon has come down and aid in recovery.

Rockets and balloons using ATV present a challenging optimum antenna radiation pattern problem similar to satellites that are predominantly flown overhead. For strongest picture and best distance (DX), the transmit and receive antennas should have their major radiation lobes pointed at each other and use the same polarization.

An omnidirectional vertical dipole antenna in the vehicle is fine for best DX on the horizon where the receiving station views the vehicle from a low angle. For example if a rocket is expected to go 1 mile vertically, receiving stations at 4 miles or more away will be within the maximum radiation lobe of the antenna and receive the best video. Receiving stations at the launch site or closer than



(A)



(B)

(C)

Fig 30 — At (A), a dipole antenna and a mirror are mounted on the outside of a 3.5 inch diameter amateur rocket. A video camera inside looks through the hole to the mirror so those receiving can see the view of the ground fall away as the rocket blasts off. At (B), N8UDK mounted an Old Antenna Lab 70 cm Little Wheel horizontal omni antenna to the bottom of his high-altitude balloon ATV payload. The camera is mounted inside the insulated foam package and looks out through the square cutout. At (C), a handheld antenna using circular polarization can be pointed at a balloon or rocket for maximum signal level as it travels. See www.hamtv.com/rocket.html.

4 miles away would be within pattern nulls.

If the rocket antenna is a ¼ wavelength vertical spike on the nose and the body of the rocket is the ground plane, the main lobe can have an up-tilt of 15 to 20° above the horizon and a significant amount of the signal will be wasted. Balloons can use an upside-down ground plane hanging below the instrument package to give a down tilt to the ground below.

At the launch site, a horizontal dipole on the rocket (see **Fig 30**) and circularly polarized antenna on the ground works best. Balloons do well by hanging an omnidirectional wheel antenna that is horizontally polarized on the horizon below the payload, but circularly polarized directly below. Circular polarization at one end helps to minimize the signal strength variation as the vehicle spins.

A 1 W, 70 cm ATV transmitter board such as the P.C. Electronics TXA5-RC series is a good tradeoff between power and battery weight. A beam antenna for reception is necessary to make up for the low power if you want snow-free pictures from higher than 20,000 feet. Typically, ATV equipment is housed in an insulated enclosure suspended below the helium-filled balloon, along with a battery capable of lasting the expected length of flight time. Styrofoam is light and will retain some of the heat dissipated from the electronics so that the extreme cold at altitude does not cause the transmitter and battery to cease operation.

Balloon and rocket groups have a lot of how-to information and often announce when there will be a launch so that hams within a few hundred miles radius can try receiving the signals. Some groups are:

Bill Brown WB8ELK Balloon Flights — **fly.hiwaay.net/~bbrown**

Arizona Near Space Research ballooning — **www.ansr.org**

Amateur High Altitude Ballooning — **www.nearsys.com**

Edge of Space Science ballooning — **www.eoss.org**

N8UDK rocket ATV — **www.detroitatvrepeater.com/rockets.htm**

KC6CCC rocket ATV — **www.qsl.net/kc6ccc/rockets.htm**

4 Video Sources

Practically any video device that delivers a picture when plugged into the coaxial video jack of a video monitor can be plugged into an ATV transmitter and used to send video over the air. Suitable sources include the composite video from camcorders, video cameras, digital cameras, VCRs or computers. The standard A/V cable from a video device has a phono plug on the end and is often identified by yellow color coding (other colors are used for audio).

The cost of video cameras has come way down, thanks to the development of solid-state imaging devices that vary in size, type and number of horizontal and vertical picture elements (pixels). Cameras widely available for home video work well for ATV.

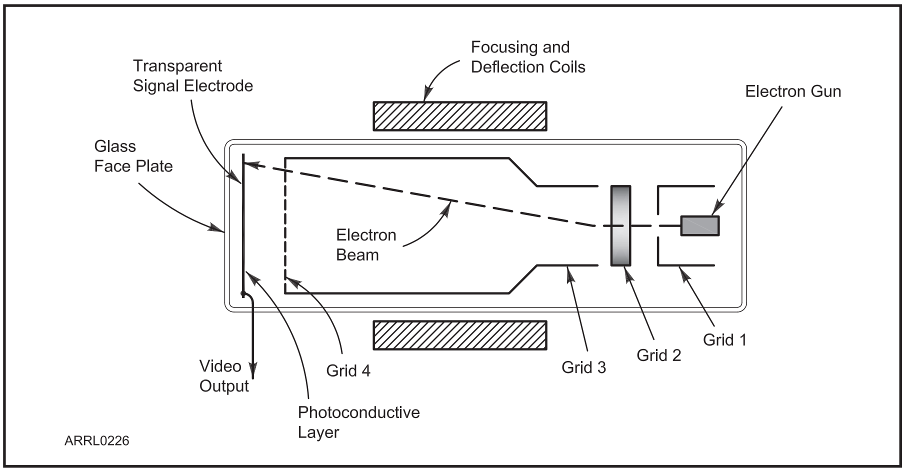


Fig 31 — The construction of a vidicon tube used for acquiring video images. Light striking the front of the tube causes the current in the electron beam from the cathode to photoconductive layer to change. These changes create the electronic video signal.

VIDICON TUBES

The vidicon is a relatively simple, inexpensive vacuum tube imaging device that once was the standard for home video cameras, closed-circuit television and ATV applications. **Fig 31** shows the vidicon's physical construction. As with a cathode ray tube (CRT), an electron beam is created by a cathode and accelerated by grids. Horizontal and vertical deflection of the electron beam in a vidicon is accomplished with magnetic fields generated by coils on the outside of the tube. Varying the strength of the fields controls the beam's position as it scans across the inside of the front of the vidicon, which is coated with a photoconductive screen layer. As the electron beam scans the screen, it charges each spot on the screen to the cathode voltage (about –20 V with respect to the signal electrode). Each spot acts like a leaky capacitor, discharging when illuminated by light hitting the front of the vidicon. The rate of discharge depends on the intensity of light illuminating the spot.

When it next scans across the spot, the electron beam will deposit enough electrons to recharge the spot to cathode potential. As it does so, the current flowing between the cathode and the screen increases, proportionally to how much the spot's "capacitor" discharged since last being scanned by the beam. Since this discharge depends on the amount of light hitting that spot on the screen, the changes in the beam current as it scans the screen correspond to the image being viewed by the screen. This creates a video signal that represents the scanned image. The variations in the beam current are very low (a fraction of a microampere), and the output impedance of the vidicon is very high, so the video circuitry must be designed with care to minimize hum and noise and the tube itself must be carefully shielded.

CHARGE-COUPLED DEVICES

A *charge-coupled device (CCD)*, in its simplest form, is made from a string of small capacitors with a MOSFET on its input and output. The first capacitor in the string stores a sample of the input voltage. When a control pulse biases the MOSFETs to conduct, the first capacitor passes its sampled voltage on to the second capacitor and takes another sample. With each successive control pulse, the input samples are passed to the next capacitor in the string. When the MOSFETs are biased off, each capacitor stores its charge. This process is sometimes described as a "bucket brigade," because the analog signal is sampled and then passed in stages through the CCD to the output.

Fig 32 shows a two-dimensional CCD that might be used in a digital camera. In a CCD used for imaging, an array of sensing elements called *pixels* are coated with light-sensitive material. The light-sensitive mate-

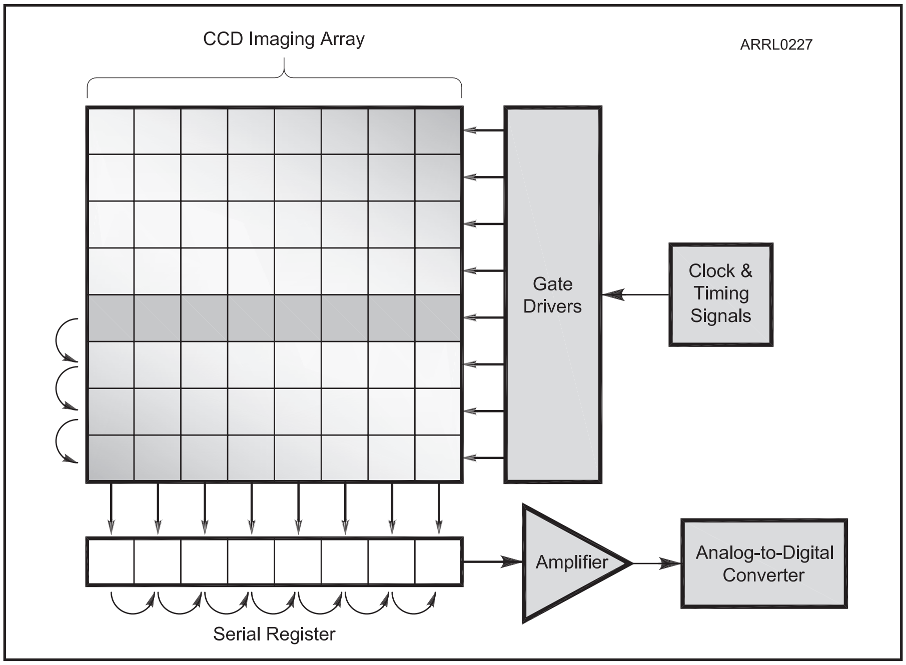


Fig 32 — The construction of a two dimensional CCD array that might be used in a digital camera. When a control pulse biases the array to conduct, the first row passes its sampled voltage on to the next row and takes another sample. With each successive control pulse, the input samples are passed to the next row until they reach the edge of the array. There they are transferred to a serial register and digitized

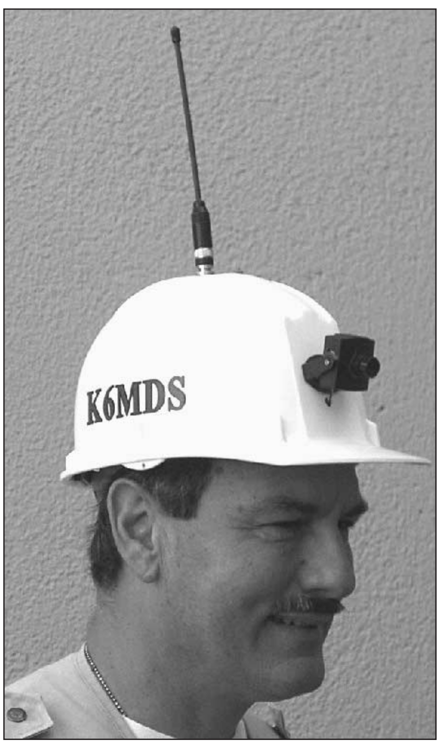


Fig 33 — Michael Saculla, K6MDS, built an ATV Hat Cam — www.hamtv.com/hatcam.html — using a CMOS color camera along with a Videolynx 70 cm transmitter for public service applications.

rial in each pixel *photocharges* a single CCD capacitor. The photogenerated charge on each capacitor is proportional to the amount of light striking the sensing element. The stored charges are then shifted out of the CCD array a line at a time as signals corresponding to each pixel. The resulting sequence of signal is similar to that of a vidicon scan. CCDs are the most common imaging device used in digital photographic cameras as well as video cameras, and they have very good low-light sensitivity.

Color CCDs use a screen called a Bayer mask over each square of four pixels. Each square has one for red, one for blue and two for green because the human eye is more sensitive to green. The luminance — gray scale — is sampled from every pixel. The possible lines of vertical resolution are determined by the number of pixels horizontally, but color resolution will be less because it comes from a square of four pixels.

When *lines of resolution* are given for a camera, this refers to the number of changes from vertical black lines to white that can be seen horizontally across the picture. While it is good to have a higher resolution camera — most are 380 lines or more — the picture will still be seen on a TV or monitor. In these display devices, response bandwidth limits luminance to about 240 lines and color to 100 lines in the NTSC system.

Fig 34 — The tiny LB-1000 420-line CMOS color camera is typical of the many low-cost devices available. Intended primarily for security applications, they are popular with amateurs.

CMOS CAMERAS

CMOS active pixel sensors are a newer development and are replacing CCDs in imaging products. CMOS cameras have lower current requirements, lower prices and less image lag, making them popular in cell phones. Amateurs use them for portable ATV applications such as the hat cam in **Fig 33**. A small CCD color camera may draw 120 mA while a comparable CMOS version draws 50 mA.

At first glance, board-level cameras are lighter for weight-sensitive applications like R/C and balloon vehicles, but those housed in a metal case are preferred to afford shielding from the effects of RF getting into the circuitry. The CMOS camera shown in **Fig 34** weighs only 3 ounces in a 1.5 inch square metal case. It also includes a microphone with line level audio output.

5 Glossary of ATV Terms

Aspect ratio — Image width divided by its height. Standard definition analog television uses an aspect ratio of 4:3 and broadcast HDTV uses 16:9.

ATSC — Advanced Television Systems Committee, the group that defined the set of standards and formats for the digital television formats implemented in the Broadcast Television Service. See **DTV**.

ATV — Amateur Television. Sending pictures by Amateur Radio. You'd expect this abbreviation to apply equally to fast-scan television (FSTV), slow-scan television (SSTV) and facsimile (fax), but it's generally applied only to FSTV.

Back porch — The blank part of a scan line immediately following the horizontal sync pulse. See **blanking**.

Black level — The signal level amplitude that corresponds to the black end of the video dynamic range.

Blanking — A "blacker-than-black" signal level that assures that the scanning trace cannot be seen as it is reset to scan another line or frame. In conventional television this is often referred to as the *blanking pedestal*, consisting of two segments — the **front porch** that precedes the vertical sync pulse and the **back porch** that follows the sync pulse.

Cathode ray tube (CRT) — A specialized electron tube, employing a phosphor-coated screen, used for image display. The classic TV "picture tube" used in older television sets and computer monitors, is an example of such a tube.

Charge-coupled device (CCD) — An integrated circuit that uses a combination of analog and digital circuitry to sample and store analog signal voltage levels, passing the voltages through a capacitor string to the circuit output.

Chrominance — The color component of a video signal. NTSC and PAL transmit color images as a black-and-white compatible luminance signal along with a color subcarrier. The subcarrier phase represents the hue and the subcarrier's amplitude is the saturation.

Cliff Effect — A phenomenon of DTV where a perfect picture disappears when the signal strength goes below a specific signal to noise ratio that the digital decoder cannot recover the number of missing bits.

CODFM — Coded Orthogonal Digital Frequency Modulation, a digital technique that uses a large number of carriers spaced slightly apart and Forward Error Correction (FEC)

Color burst — Seven cycles of a 3.58 MHz subcarrier signal located on the back porch (see **blanking**) of an NTSC color TV signal waveform. This short burst is locked on to by a PLL in the TV receiver as the reference for the chroma in the video.

Color subcarrier — The modulated 3.58 MHz component of an NTSC color television signal that is used to convey the color or luminance image data.

Composite video — The standard 1 V peak to peak analog video into 75 Ω load signal consisting of color, video, blanking and sync found in consumer products and typically identified with a yellow color coded RCA connector. The sync tip is referenced at 0 V, blanking at 0.285 V, black level at 0.339 V and white at 1.0 V.

Compression — Various digital techniques to reduce the bandwidth, transmission rate or file size of an image.

D-CATV — Digital Cable TV. In the USA, QAM modulation using the North American ITU-T-J83-B protocol

Deflection — the circuits or other components controlling the vertical and horizontal sweep signals that move the scanning beam of a cathode ray tube image display.

DTV — Digital television, most commonly applied to a series of 16 digital formats (including HDTV or High Definition Television) that comprise the default commercial broadcast digital TV standards in the United States.

DVB-C — Digital Video Broadcast — Cable. Uses QAM modulation. The European DVB-C coding protocols are different and incompatible with USA televisions. The EU has an 8 MHz bandwidth and the North American ITU-T-J83-B digital cable protocol operates in 6 MHz.

DVB-S — Digital Video Broadcast — Satellite. Uses QPSK modulation.

DVB-T — Digital Video Broadcast — Terrestrial. Uses CODFM modulation.

Field — Collection of top to bottom scan lines. When interlaced, a field does not contain adjacent scan lines and there is more than one field per frame.

Frame — One complete scanned image. NTSC has 525 lines per frame with about 483 usable after subtracting vertical sync and a few lines at the top containing various information.

Front porch — The blank part of a scan line just before the horizontal sync.

FSTV — Fast-Scan TV. Same as common, full-color, motion commercial broadcast TV.

Interlaced scanning — A scanning pattern, designed to reduce perceived flicker in broadcast television systems, in which the complete image frame is actually made up from two sequentially-scanned fields and thus improving the vertical resolution. The timing of the sequential scanning is such that the lines of the second field are interspersed between the lines of the first field. For example, NTSC sends a field with just the even lines in 1/60 second, then a field with just the odd lines in 1/60 second.

Luminance — The brightness component of a video signal and can refer to the white-to-black amplitude or the chroma weighted sum of the gamma-compressed R'G'B' components computed as Y (the luminance signal) = 0.59 G (green) + 0.30 R (red) + 0.11 B (blue).

MPEG — Motion Picture Experts Group, a set of digital image compression formats/standards for moving images.

North American Cable Standard — A digital TV protocol that is used in cable systems in the USA to the ITU-T J.83B standard.

NTSC — National Television System Committee. Analog broadcast television standard used in North America and Japan.

PAL — Phase alteration line. Analog television standard used in Germany and many other parts of Europe.

Progressive scanning — A scanning sequence in which all image lines are scanned sequentially to display the complete image frame. Used in some **DTV** broadcasts.

Pixel — Picture element, the dots that make up images on a monitor. Image resolution is directly related to the number of picture elements. If the size of a picture element is large relative to total image size, the image will be made up of a relatively small number of picture elements and thus have relatively poor resolution. If the size of a picture element is small relative to total image size, the image will consist of a large number of picture elements and thus demonstrate better resolution.

QAM — Quadrature Amplitude Modulation. A method of simultaneous phase and amplitude modulation. The number that precedes it, for example 64-QAM, indicates the number of discrete combinations of phase and amplitude in each pulse and known as symbols. Each symbol represents, in this case, a 6 bit digital stream — 256-QAM would represent 8 bits.

QPSK — Quadrature Phase Shift Keying. A form of Phase Shift Keying in which two bits are modulated at once with one of four possible carrier phase shifts (0, 90, 180, or 270 degrees).

Raster — The pattern of scanning lines developed on the face of a cathode ray tube during the display of one image frame.

Resolution — The ability to see a number of vertical lines horizontally across the screen. The NTSC analog horizontal scan rate of 15734 Hz limits the luminance resolution to 80 lines per MHz of video response bandwidth. Digital TV's highest resolution is limited by the number of screen pixels. It takes 2 adjacent pixels, one black and one white for one line.

RGB — Red, Green, Blue. One of the models used to represent colors. Due to the characteristics of the human eye, most colors can be simulated by various blends of red, green, and blue light.

SECAM — Sequential color and memory. Analog television standard used in France and the Commonwealth of Independent States.

Sync — That part of a TV signal that indicates the beginning of a frame (vertical sync) or the beginning of a scan line (horizontal sync).

Vidicon tube — A type of photosensitive vacuum tube used in TV cameras.

White level — The white end of the video dynamic range in any image transmission format. The difference between white and black levels defines the video dynamic range of the mode.

Virtual Channel — A channel number that is not the same as the actual occupied channel to make it easier on cable subscribers. For instance a network is analog on cable channel 8, but its digital channel can be shown as 8.1 on its info video overlay even though it occupies a higher channel, typically above channel 69.

VSB — Vestigial Sideband. FCC Rule 73.681 defines it as "A system of transmission wherein one of the generated sidebands is partially attenuated at the transmitter and radiated only in part." Broadcast standard is to favor the Upper Vestigial Sideband (U-VSB or just VSB) and partially attenuate the lower sideband. Some ATV repeaters for interference and local band plan reasons favor the Lower Vestigial Sideband (L-VSB).

8-VSB — 8-level Vestigial Side Band, the standard for broadcast **DTV** in the US.

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7 Slow-Scan Television (SSTV) Overview

The previous sections discussed fast-scan amateur television, used to send wide-bandwidth full motion video in the 420 MHz and higher bands. In contrast, slow-scan television (SSTV) is a method of sending still images in a narrow bandwidth and is widely used on the HF bands, although SSTV is sent via FM repeaters and amateur satellites too. **Fig 35** shows a sample image.

Images are our most powerful communication tool. They can help us understand and remember better than any of our other senses. SSTV allows us to add images to our verbal communications via Amateur Radio. Working with the SSTV mode can provide much more than just swapping pictures. It provides a practical way to learn about radio propagation, computers and computer graphics. As with any activity, the more involved you become, the more knowledgeable you become about all the intricacies.

Fig 35 — Color SSTV image received from the International Space Station in Martin 1 mode 10/12/08 on 145.800 MHz FM.

SSTV is also a great way to get others involved in Amateur Radio or enhance other activities. Consider adding SSTV capability to your emergency communications, public service, Field Day or Jamboree on the Air station.

7.1 SSTV History

SSTV originally involved the transmission of a visual image from a live video source.

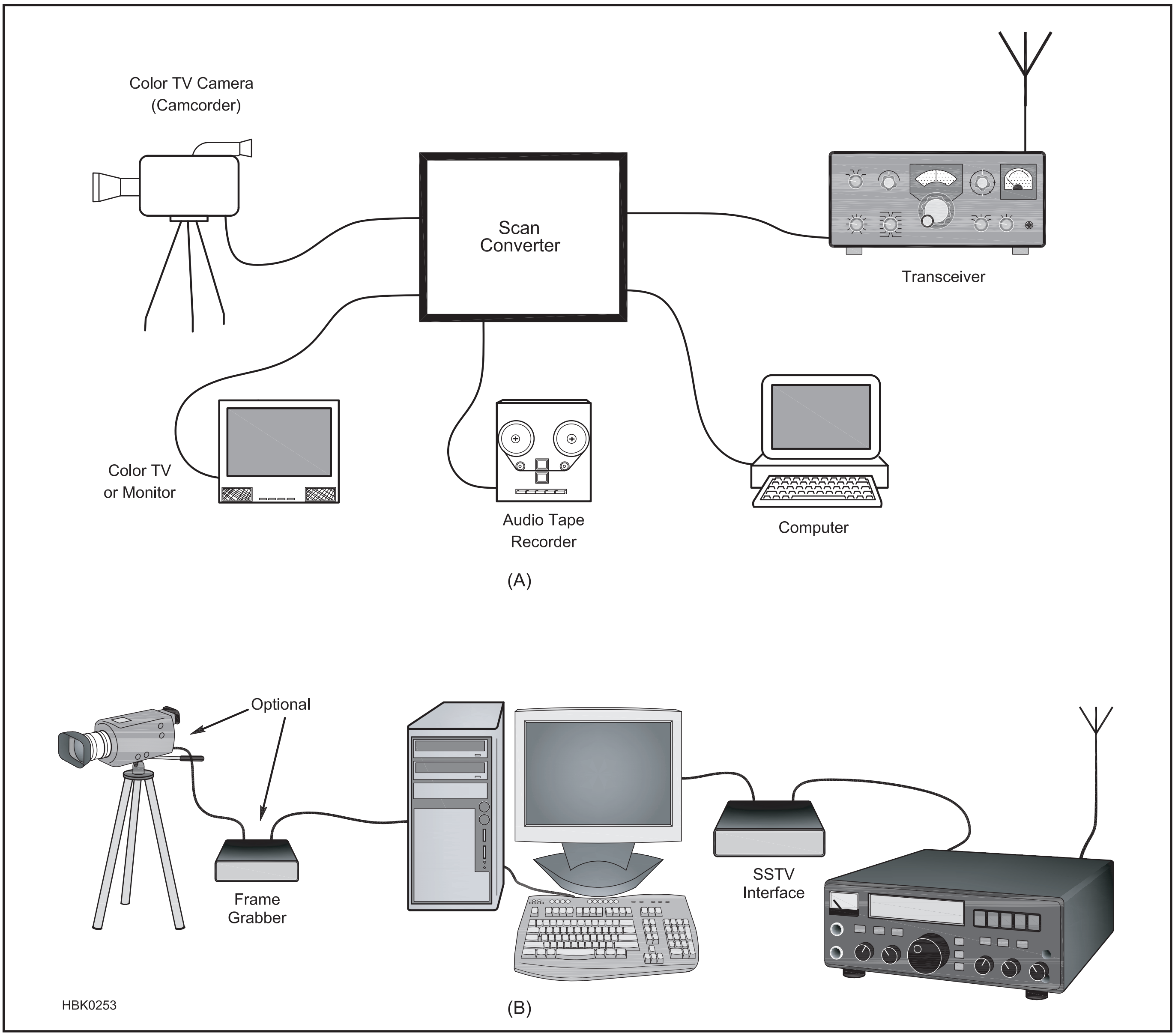


Fig 36 — Older SSTV stations required a dedicated hardware scan converter (A). Modern stations need only a sound card equipped PC and simple interface to send and receive SSTV (B).

Images were black-and-white. Specific audio tones represented black, white and shades of gray, while other audio tones were used for control signals. The receiving station converted the tones back into an image for display on a picture tube. It took 8 seconds to send a picture, and everything fit in the same bandwidth used for SSB transmissions.

Copthorne Macdonald, WA2BCW, now VY2CM, developed the first SSTV system. In 1958, MacDonald used a surplus long-persistence phosphor radar monitor to display SSTV images. The images were created using a vidicon camera or a flying-spot scanner. One frame of video had 120 lines and was sent at a rate of 15 lines per second (that's where the 8 seconds fits in). Three frames were sent back-to-back to maintain an image on the monitor. For many years, home-built systems were the only way to participate in SSTV. These were bulky, expensive and complex.

Robot Research produced SSTV equipment throughout the 1970s and 1980s. Their Robot 1200C scan converter, introduced in 1984, represented a giant leap forward for SSTV — all the SSTV functions were performed within a single box. (A *scan converter* is a device that converts signals from one TV standard to another. In this case, it converted SSTV signals to and from devices intended for fast scan television.) With updates and modifications, many 1200Cs are still in use today.

DOS-based PCs became a popular component for SSTV systems in the early 1990s. These hybrid systems were part hardware and part software. Most systems had an external box that processed the audio and performed the analog-to-digital conversion. In 1998, the Tasco Electronics TSC-70 Telereader color scan converter was used on the MIR space station to send pictures from space. Kenwood introduced Visual Communicator VC-H1, a portable SSTV unit that included a built-in camera and LCD monitor. Other scan converters were made, but none are produced today.

The personal computer with sound card has become the hardware of choice to send and receive images, replacing specialized devices. Today's powerful PCs and SSTV software are the heart of a modern SSTV station. The PC processes the incoming and outgoing SSTV audio using the sound card, while the software manages the acquisition, storage, selection and editing of the SSTV pictures. If you have a PC in your ham station, adding software and an interface (to connect the computer sound card to the transceiver) is all that it takes to get started in this fascinating mode. **Fig 36** compares a current station SSTV configuration to one from the 1990s.

8 SSTV Basics

Traditional SSTV is an analog mode, but in recent years several digital SSTV systems have been developed. All make use of standard Amateur Radio transceivers — no special radio gear or antennas required. SSTV transmissions require only the bandwidth of SSB voice, and they are allowed on any frequencies in the HF and higher bands where "Image" transmissions are permitted, generally the same band segments as for SSB voice signals. SSTV does not produce full motion video or streaming video.

8.1 Computers and Sound Cards

A computer with sound card is required to use most of the software popular for SSTV. Software for the *Windows* operating system is the most popular, but other choices are available. Hardware and software setup is similar to that described for sound card modes in the **Digital Communications** chapter on the *Handbook* CD-ROM.

The sound card characteristics discussed in the **Digital Communications** chapter apply to SSTV as well. Most sound cards will work, but sample rate accuracy is important for some SSTV modes (more on this later).

Within *Windows*, the MASTER VOLUME and WAVE controls set the levels for the transmitted SSTV audio. All other mixer inputs should be muted. Equalizer and special effects should not be used. *Windows* sounds should be disabled to prevent them from being transmitted along with the transmitted SSTV audio. The RECORDING control is used to select the input for receiving the SSTV audio. Adjust LINE IN or MICROPHONE as needed for the proper level. MIC BOOST should not be used.

8.2 Transceiver Interface

Interfacing the transceiver to the PC sound card can be as simple as connecting a couple of audio patch cables. Sound cards generally have stereo miniature phone jacks, so use matching plugs when making these connections. Only one audio channel is required or desired — the left channel. This is the tip connection on the plug. Use shielded cable with the shield connected to the sleeve (ground) on the plug. Ground loop problems may be avoided by using an audio isolation transformer.

The connection for receiving the SSTV audio from the transceiver may be made anywhere that received audio is available. The best choice is one that provides a fixed-level AF output. This will ensure that recording control levels will not have to be adjusted each time the volume on the transceiver is adjusted. You can use a headphone or speaker output if that's all that is available. If the received output level is enough for the LINE IN input on the sound card, use it, otherwise use the MICROPHONE input. If the level is too high for LINE IN, an attenuator may be required.

Use the LINE OUT connection on the sound card for the transmitted SSTV audio output. The cable for transmitted SSTV audio should go to the AFSK connection. If the transceiver does not have a jack for this, then the microphone jack must be used — requiring a more elaborate interface. TR keying can be provided using the transceiver's VOX. Other methods for activating transmit include manual switching, a serial port circuit, an external VOX circuit, and/or a computer-control command.

Commercially made and kit sound card interfaces are available. Most of the sound card interfaces for the digital modes are suitable for SSTV. The microphone will be used regularly between SSTV transmissions, so consider its use along with the ease of operation when setting up for SSTV.

For more information on interfaces and adjustments, see the **Digital Communications** chapter on the *Handbook* CD-ROM. Another useful resource is the sound card interface web page by Ernie Mills, WM2U, at **www.qsl.net/wm2u/interface.html.**

8.3 Transceiver Requirements

An SSB voice transceiver with a stable VFO is necessary for proper SSTV operation. The VFO should be calibrated and adjusted to be within 35 Hz of the dial frequency (more on this later). The transceiver's audio bandwidth should not be constrained so as to attenuate the audio spectrum used by SSTV. Optional filters should be turned off unless they can be set to 3 kHz or wider. SSTV software has its own DSP signal processing tools, so they are not needed in the transceiver. Most of the other transceiver settings should be turned off, including transmit or receive audio equalization, noise blanker or noise reduction, compression or speech processing, and passband tuning or IF shift.

Adjust your transmitter output for proper

operation with the microphone first, according to instructions in your manual. Then adjust the sound card output for desired drive level. For SSB operation, receiving stations should see about the same S meter reading on the SSTV signal as for voice. Properly adjusted levels and clean audio quality will improve the reception of the transmitted signal as well as reduce interference on adjacent frequencies. The SSTV signal is 100% duty cycle. If your transceiver is not designed for extended full-power operation, reduce the power output using the *Windows* VOLUME CONTROL.

SSTV may be transmitted using AM, FM or SSB. Use the same mode as you would use for voice operation on a given frequency. On HF, use the same sideband normally used for voice on that band. SSTV activity can be found on HF, VHF, UHF, repeaters, satellites, VoIP on the Internet and almost anywhere a voice signal can get through.

8.4 SSTV Operating Practices

Analog SSTV images are, in a sense, broadcast. They arrive as-is and do not require the recipient to establish a two-way connection. Most SSTV operation takes place on or near specific frequencies. Common analog SSTV frequencies include 3.845, 3.857 and 7.171 MHz in LSB and 14.227, 14.230, 21.340 and 28.680 MHz in USB. Establish a contact by voice first before sending SSTV. If no signals can be heard, on voice ask if there is anyone sending. It may be that someone is sending but you cannot hear them. If there is no response, then try sending a "CQ picture." Note that on popular frequencies, weak signals can often be heard. In this case, wait for traffic to finish before sending SSTV even if you got no response to your voice inquiry.

Receiving SSTV pictures is automatic as long as your software supports the mode used for transmission (more on SSTV modes in later sections). Once a picture is received, it will be displayed and may be saved.

When selecting images to send, consider appropriateness, picture quality, and interest to the recipient. Choose an SSTV mode that is suitable for the image to be sent, band conditions, signal strengths and the recipient's receive capability. Announce the SSTV mode prior to sending. Avoid sending a CW ID unless required by regulations. Describe the picture only after it is confirmed that it was properly received.

To send SSTV, use your software to select and load a picture to send. It will be displayed in a transmit screen. Next, select the SSTV transmission mode. Click the transmit button, and your transceiver will switch to transmit and send the SSTV audio. When the SSTV transmission is over, the transceiver returns to receive. Be sure to send the full frame or the next picture sent may not be received properly because it may not start scanning from the top.

SOURCE FOR IMAGES

The Internet is a popular source for images. With the unlimited number of images available, it is surprising how often the same internet pictures keep popping up on SSTV. Use a little imagination and come up with something original.

A digital camera is one of the best ways to create an original picture of your own. The subject matter could be almost anything that you might have available. Pictures of the shack, equipment and operator are always welcomed. A live camera or webcam can provide an almost instant snapshot. Please keep your shirt on and comb your hair!

For those who like to discuss technical details, diagrams and schematics might be your ammunition. A flatbed scanner is ideal for importing diagrams, schematics and photographs. Screen shots of what is on the computer monitor can be saved simply by hitting the PRINT SCREEN key on the keyboard. Use the PASTE function in *Windows* to transfer the image to your SSTV or image editing software.

Any image editing program can be used to make your own CQ picture, test pattern, video QSL card or 73 picture. Include your own personal drawings. Make your images colorful with lots of contrast to make them really stand out. You can also transmit pictures of your home, areas of local interest, other hobbies, projects, maps, cartoons and funny pictures.

It is common to have call sign, location and perhaps a short description as text on the pictures. If two calls are placed on an image, it is understood that the sender's call is placed last. Signal reports may also be included. Once the images are saved, they provide a convenient confirmation of contact.

9 Analog SSTV

With slow scan, the fastest frame rate is eight seconds so full motion video is not possible. Analog SSTV sends only one tone at any time. A 1200 Hz sync pulse is sent at the beginning of each line. Pure black is represented by a 1500 Hz tone, and 2300 Hz is used for pure white. Tones between 1500 and 2300 Hz produce the grayscale. The frequency varies with the brightness level for each pixel. Since it is only the change in frequency that makes up the analog SSTV signal, it is considered frequency modulated. Amplitude is not important other than being heard over the noise. Analog SSTV uses less bandwidth than voice.

9.1 Color SSTV Modes

Two popular modes for sending and receiving color SSTV pictures are called Martin and Scottie (named after their developers). Within each family are several different modes (Martin 1, Martin 2 and so forth). The various modes have different resolutions and scan rates.

Information about the size or resolution for each mode is generally available in the SSTV software. Better quality images will result when the source image is sized and cropped to the same dimensions used by the mode with which it is transmitted. Slower scan rates can provide better quality; those are the modes that take longer to send for the same resolution.

For example, Scottie 1 and Martin 1 are popular RGB (red, green, blue) color modes that take about two minutes to send a frame, with only one frame sent at a time. The image size sent is 320 × 256 — 320 pixels across with 256 lines. See **Figs 37** and **38**. True color is possible since each pixel is sent with 256 possible levels for each of the three color components (red, green and blue).

Each mode has a vertical interval signaling (VIS) code that identifies the mode being sent. The VIS codes use 1100 Hz for 1, 1300 Hz for 0, and 1200 Hz for start and stop. When these tones are received, it readies the system to receive in the proper SSTV mode.

For VIS detection to work, the receiver must be tuned within 70 Hz of the transmitted frequency. Two stations tuned exactly on the SSTV frequency but with VFO errors of +35 Hz and –35 Hz could successfully pass the VIS codes. As mentioned previously, each transceiver must have the VFO and display calibrated within 35 Hz to ensure VIS code detection with the transceiver set to the SSTV frequency. Using the sync pulse rate is another way to determine the mode when the VIS is not decoded. If a station sending is far off frequency, use the 1200 Hz sync signal in the spectrum or waterfall as a guide to adjust the VFO.

Received images are displayed in near real

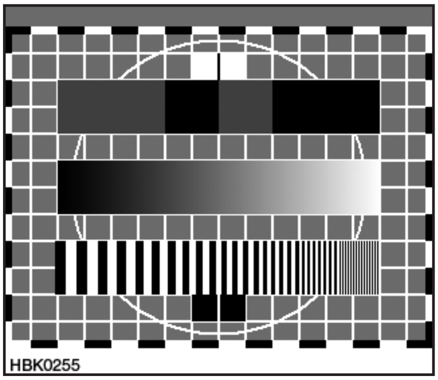


Fig 37 — This color test pattern is 320 × 256 resolution. The Robot modes from the 1980s only used 240 lines. CRTs were 4:3 aspect ratio, so the images were displayed in 320 × 240 resolution. When Scottie 1 and Martin 1 modes were added, they kept this resolution but added 16 header lines to the top to aid in synchronization. These 16 header lines, shown as the solid gray area at the top, are now used as part of the image and include the sender's call sign and other information.

Table 2
SSTV Software

Windows
Analog SSTV
ChromaPIX — **www.barberdsp.com/cpix/chroma.htm**
MMSSTV — **hamsoft.ca/pages/mmsstv.php**
Mscan — **mscan.com/?page_id=2**
ROY1 — **www.roy1.com/download_ita.htm**
SSTV32 — **webpages.charter.net/jamie_5/**
W95SSTV — **www.barberdsp.com/w95sstv/w95sstv.htm**

Multimode
JVComm32 — **jvcomm.de/index_e.html**
MixW — **www.mixw.net**
MultiPSK — **f6cte.free.fr/index_anglais.htm**

Digital SSTV
DIGTRX — **qslnet.de/member/py4zbz/hdsstv/HamDRM.htm**
EasyPal — **vk4aes.com**
WinDRM — **n1su.com/windrm/**

MacOS
MultiMode — **www.blackcatsystems.com/download/multimode.html**
MultiScan — **multiscan.mac.informer.com/2.0/download/**

Linux
QSSTV — **users.telenet.be/on4qz/**
RXAMADRM — **www.pa0mbo.nl/ties/public_html/hamradio/rxamadrm/index.html**

Amiga
AVT — **datapipe-blackbeltsystems.com/amiga.html**

For links to additional software and notes on setup and operation, see **www.qsl.net/kb4yz/**

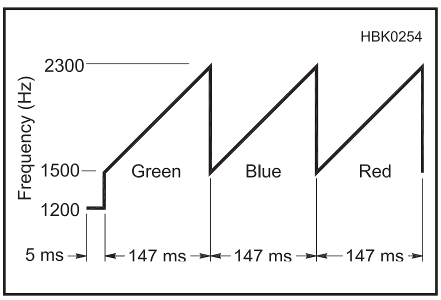


Fig 38 — This is a diagram of a single scan line of a Martin 1 transmission. The full frame includes 256 horizontal scan lines starting at the top. Before each line, a 1200 Hz tone for 5 ms is sent for synchronization. The pixels are scanned left to right and the colors are sent sequentially. First the green component is sent for each of the 320 pixels of one scan line — 256 values are possible from black to pure green. Next, is the blue component, and the red component is sent last (again, 256 possible values for each color). It takes 147 milliseconds to send each of the three color components. The result is 114 seconds to send the complete frame.

time as they are decoded. Almost any SSTV signal that is heard can produce an image, but it is rare to receive an image that is perfect. Changes in propagation or transceiver settings will become apparent as the image continues to scan down the screen. Noise will damage the lines received just as it occurs. Interference from other signals will distort the image or perhaps cause reception to stop. Signal fading may cause the image to appear grainy. Multipath will distort the vertical edges. Selective fading may cause patches of noise or loss of certain colors.

Images that are received with staggered edges are the result of an interruption of the sound card timing. Check with other operators to see if they also received the image with staggered edges. If not, then it may be your computer that has the problem and not the sending station. Some possible solutions are to close other programs, disable antivirus software and reboot the computer.

Under good conditions, images may come in "closed circuit." This means that the quality appears nearly as good as a photograph. SSTV has a reporting system similar to the RST reporting system used on CW. For analog SSTV it is RSV — readability, signal strength and *video*. Video uses a scale of 1 to 5, so a report of 595 would be the same as closed circuit.

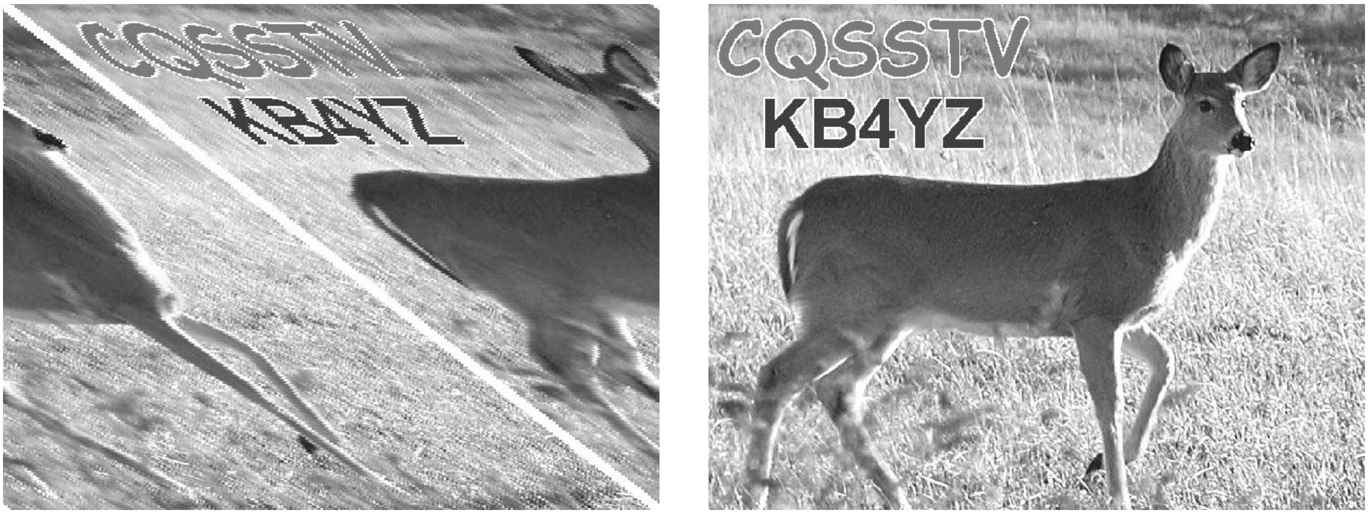
9.2 Analog SSTV Software

A variety of software programs are available for SSTV (see **Table 2**). Some multimode programs include SSTV and digital modes, while others are dedicated to SSTV. One very popular SSTV package is the *Windows* program *MMSSTV* by Mako Mori, JE3HHT. For more information or to download a copy, visit **hamsoft.ca/pages/mmsstv.php**. *MMSSTV* will run on an old 100 MHz PC, but some features may require a faster processor. Other SSTV software has similar features.

As explained in the **Digital Communications** chapter on the *Handbook* CD-ROM, sound card sample rate accuracy is important for some modes. Analog SSTV is one of them: pictures will appear *slanted* if the clock is off. See **Fig 39**. The *MMSSTV* Help file includes detailed information on several ways to do a quick and easy calibration (see the Slant Corrections section). The best method is the one that uses a time standard such as WWV. (Before performing this calibration procedure, you must have the sound card interface connected so *MMSSTV* can detect received audio.) After performing the clock calibration, chances are the timing will also be correct for transmit. If not, *MMSSTV* provides a means for making a separate adjustment for transmit.

9.3 Resources

The International Visual Communications Association (IVCA) net meets each Saturday morning at 1500 UTC on 14.230 MHz USB.



(A) (B)

Fig 39 — If the sound card clock is inaccurate, analog SSTV images may appear slanted (A). The same image is shown at B after calibrating the clock.

The net control will ask for check-ins and get each station to send a picture in Scottie 1 mode. Replays are sent in Scottie 2 mode. This will provide a way to see how well your pictures were received. Signal reports are welcome and brief questions may be asked. Anything more involved should be held until the net is over. Anyone may check-in to the net.

Information about the IVCA is available on Yahoo Groups: **groups.yahoo.com/group/ivca**. The *MMSSTV* Yahoo group is another valuable resource: **groups.yahoo.com/group/MM-SSTV**.

10 Digital SSTV

Several forms of digital SSTV have been developed, but the modulation method most widely used for digital SSTV as of 2009 is derived from the shortwave broadcast system Digital Radio Mondiale (DRM). (See the **Digital Communications** chapter on the *Handbook* CD-ROM for more information on Amateur Radio digital voice (DV) applications.) *HamDRM,* by Francesco Lanza, HB9TLK, is a variation of DRM that fits in a 2.5 kHz bandwidth and is used in various programs.

The DRM digital SSTV signal occupies the bandwidth between 350 and 2750 Hz (see **Fig 40**). As many as 57 subcarriers may be sent simultaneously, all at the same level. Three pilot carriers are sent at twice the level as the others. The subcarriers are modulated using *coded orthogonal frequency division multiplexing* (*COFDM*) and *quadrature amplitude modulation* (*QAM*). Each *main service channel* (*MSC*) frame or segment has 400 ms duration, and several methods of error correction are used within the segments. (See the **Modulation** chapter for more information on ODFM and QAM.)

Digital SSTV using DRM is not a weak signal mode like the narrow bandwidth data modes such as PSK31. An S9 or better signal with little or no noise may be required before the software is able to achieve a sync lock. MSC sync lock is required before any data is received.

10.1 Digital SSTV Setup

A popular DRM digital SSTV program is *EasyPal* by Erik Sundstrup, VK4AES (**www.vk4aes.com**). Digital SSTV uses the same type of PC and sound card setup described in the analog SSTV section, but a more capable computer is required. For *EasyPal*, a 2 GHz or faster PC running *Windows XP* or newer operating system is required. As soon as the *EasyPal* software is installed, it is ready to receive pictures.

Unlike analog SSTV, the software detects and compensates automatically for clock timing differences so sound card calibration is not required. Software will also automatically adjust ±100 Hz for mistuned frequency.

With DRM SSTV the call sign is sent continuously. This may allow others to identify the transmitting station and perhaps turn an antenna in the right direction for better reception. Many submodes are available, with various transmission speeds and levels of robustness. The submode is automatically detected and receiving starts automatically. Decoding is done on the fly, so there is no waiting for the computer to finish processing before the image appears.

Power output may appear low as measured by a conventional wattmeter. The actual signal strength as seen by others should be about the same as the SSB voice signal. Avoid series capacitors for blocking dc in the audio lines as they may interfere with the phase of the digital signal.

DRM audio levels are low, so there may be problems getting the signal to trigger a VOX circuit. Set the transceiver for full RF output. Then adjust the sound card Volume Control output until the transmitter shows little or no ALC indication. With an FM transmitter, keep the output level low to avoid overdeviation.

10.2 Operating Digital SSTV

Before jumping into digital SSTV, try analog SSTV first. Copy some pictures to see if the sound card setup works. The level adjustments for analog SSTV are not as critical as those for DRM.

Common DRM SSTV frequencies include 3.847, 7.173, 7.183 MHz in LSB and

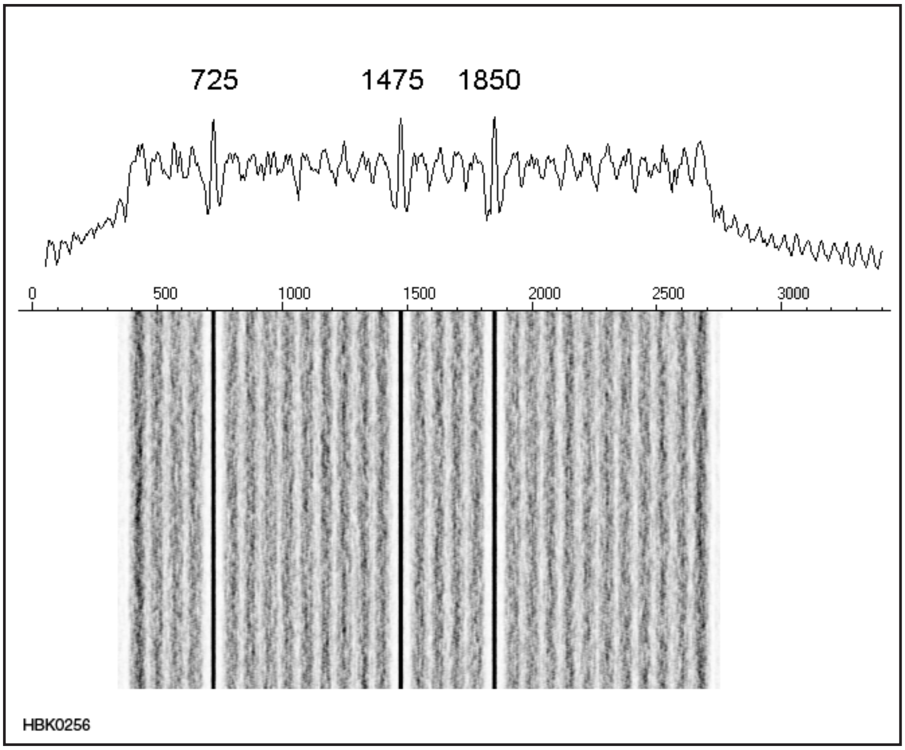


Fig 40 — DRM signal spectrum above and waterfall display below. DRM transmissions may have slightly different characteristics due to the many possible submodes. All DRM transmissions used in Amateur Radio have three pilot carriers that have an amplitude twice that of the remaining subcarriers. These pilot carriers are found at 725, 1475 and 1850 Hz and aid in adjusting the frequency of the receiver to match the transmitted signal. The DRM TUNE signal also matches these three carriers. Software can compensate for mistune for as much as ±100 Hz, but only if the difference remains stable (little or no drift in frequency). The overall response should be flat, producing a level amplitude across the full spectrum provided that the signal is not affected by propagation. The waterfall should also be nearly the same intensity across the full width. The bandwidth can be as much as 2.4 kHz, starting at 350 Hz and ending about 2750 Hz. Some roll-off can be tolerated.

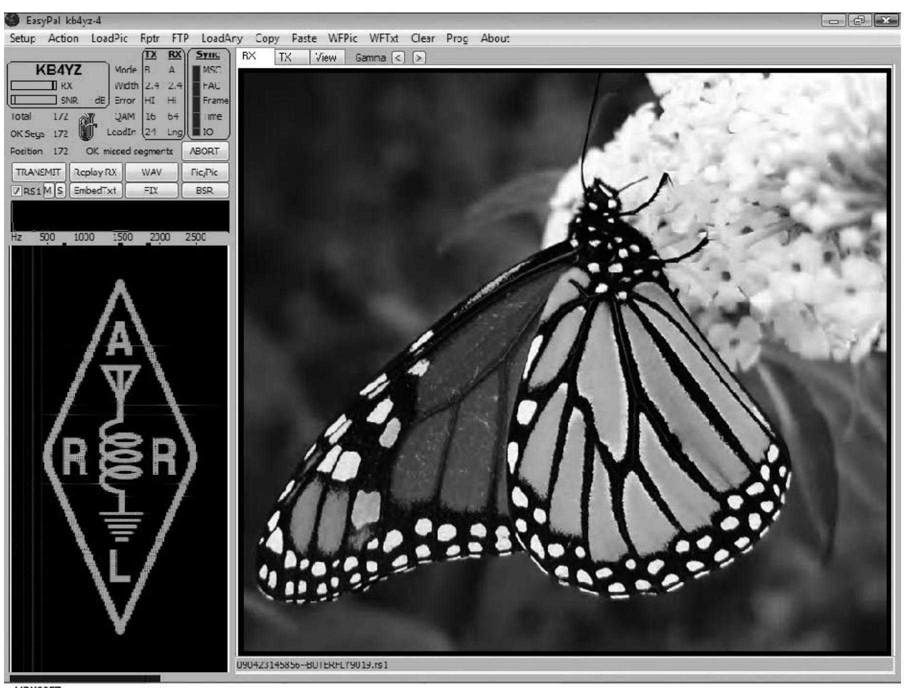


Fig 41 — *EasyPal* DRM digital SSTV software is used to exchange high quality, color images. Several levels of error correction and various transmission speeds are available.

14.233 MHz in USB. Tune your VFO to the whole number in kHz (for example, 14,233.0). If a sending station is far off frequency, use the pilot carriers as seen in the software spectrum display as a guide. Adjusting the VFO while receiving an image is not advised as it will delay synchronization.

The signal-to-noise ratio (SNR) as displayed in the software is a measure of the received signal quality. The higher the SNR the better — decoding will be more reliable. Under very good band conditions this number may exceed 18. In that case, a higher speed mode may work. Because of the way the software measures the SNR, the peak value displayed for SNR may require 20-30 seconds of reception. Adjustments made on either end may change the SNR. Submodes with less data per segment take longer to send, but they are more robust and allow for copy even if the SNR is low.

GETTING THE WHOLE PICTURE

Noise and fading may prevent 100% copy of all the segments. Any missing segments may be filled in later. Your software can send a *bad segment report (BSR)* that lists all the missing segments for a file that has only been partly received. In response, the other station can send a *FIX* which should complete the file transfer. If not, the BSR and FIX process may be repeated.

Digital SSTV is very interactive and may involve several stations on frequency sharing images. FIX transmissions intended for another station may provide some of your missing segments — or even all of them. A third party that copied the original transmission may also send a FIX or resend the image. Incremental file repair is possible even after several other transmissions are received. The more stations on frequency, the better the chance that one of them is in a position to help out with a FIX.

EasyPal has a feature to provide a higher level of error correction so that 100% copy of all the segments is not necessary to receive the complete file. The transmitted file is encoded with redundant data so that the original file may be recreated even though not all the segments were received. The receiving station must also be running *EasyPal*.

Encoded files have interleaved redundancy using Reed-Solomon (RS) error correction. (See the **Digital Modes** chapter for more information about error detection and correction.) Four different levels of RS encoding may be selected before the file is sent.

Very Light Encode (RS1) is the lowest level. Transmission time for a file using RS1 will be increased by 13%. When receiving a file encoded with RS1, only 90% of the segments must be received before the file can be decoded and a picture displayed. This may happen even before the transmission is complete. Receiving RS encoded files is automatic; there is no need to select it for receive. Decoding of the file received with RS encoding will occur automatically. The use of RS encoding on the HF bands can reduce the need for BSRs and FIXs and has been found to make the file transfer process more efficient. Encoding may not be necessary on noise-free channels such as VHF FM.

Propagation becomes a factor only as it may take longer for the data to get through during poor conditions. The images received will be identical to the ones sent because the data in the files will also be identical. Replays will always be an exact copy. Multipath propagation does not disrupt DRM transmissions unless it is severe or results in selective fading.

Fig 41 shows an *EasyPal* screen following successful reception of an image.

IMAGE SIZE

Pictures of any size or resolution may be sent over digital SSTV. The sending station must pay careful attention to file size, though, or the transmission time may become excessively long. Compressing image files is necessary to get the transmit time down to a reasonable amount. Most images will be converted into JPEG 2000 (JP2), a lossy compression method that shows fewer artifacts. A slider varies the JP2 compression level, and a compromise must be made between image quality and file size. The smaller the file, the more visible the artifacts, but the faster it is sent.

Small image files may be sent without using compression. Some file types such as animated GIF files cannot be compressed, so they must be sent "as is."

A "busy picture" is one that shows lots of detail across most of the image area. This type of picture can be challenging to compress into a file size small enough to send that still maintains acceptable quality. Reducing the resolution by resizing and creating a much smaller image is the solution. Just about any busy picture can be resized down to 320 × 240 pixels, converted into JP2, and still look good when displayed on the receiving end.

About two minutes of transmission time is the acceptable limit for the patience of most SSTV operators. A typical DRM digital SSTV transmission will take about 105 seconds for a file 23 kB in size, RS1 encoded and requiring 209 segments.

SENDING DIGITAL SSTV IMAGES

The ideal DRM signal will have a flat response across the 350 to 2750 Hz spectrum. The transceiver should be allowed to pass all frequencies within this bandwidth. In order to maintain the proper phase relationships with all the subcarriers, the signal must be kept linear. Avoid overdriving the transmitter and keep the ALC at the low end of the range. Eliminate hum and other stray signals in the audio.

The process of transmitting an image starts with selecting an image and resizing or compressing it if needed, as described in the previous section. Within *EasyPal*, when the transmit button is clicked, the image file will be RS encoded if that option is selected. Then the resulting file will be broken down into segments and sent using DRM.

In receiving DRM, the audio is decoded and segments that pass the error check will have their data stored in memory. When enough of the segments are successfully received, the RS file is decoded and the JPEG 2000 image file is created. The content of this file should be identical to the JPEG 2000 image file transmitted.

It can be quite gratifying to receive your first digital SSTV picture. A lot has to go just right, and there is little room for errors. Propagation and interference always play havoc. There is no substitute for a low noise location and good antenna when it comes to extracting the image from the ether. Be patient and when the right signal comes by you will see the all the lights turn green and the segment counter will keep climbing. You won't believe the quality of the pictures!

Help for all aspects of digital SSTV is available on Yahoo Groups DIGSSTV: **http://groups.yahoo.com/group/digsstv.**

10.3 Future of SSTV

Advancements in radio technology should make SSTV easier. Software defined radios (SDR) that make use of direct conversion of audio signals and use "virtual cables" internally may eliminate RF pickup and other forms of noise. Higher SNR should result. New transceivers that make use of optical cables may avoid problems with noise getting into or coming out of the sound card. All this could mean less distortion, lower noise levels and reduced hum and improved image quality. New digital SSTV systems will certainly be on the way. New features for DRM digital SSTV are being developed and new ways to use digital SSTV are discovered every day.

11 Glossary of SSTV Terms

AVT — Amiga Video Transceiver. 1) Interface and software for use with an Amiga computer; 2) a family of transmission modes first introduced with the AVT product.

Back porch — The blank part of a scan line immediately following the horizontal sync pulse.

Chrominance — The color component of a video signal. Robot color modes transmit pixel values as luminance (Y) and chrominance (R-Y [red minus luminance] and B-Y [blue minus luminance]) rather than RGB (red, green, blue).

Demodulator — For SSTV, a device that extracts image and sync information from an audio signal.

Field — Collection of top-to-bottom scan lines. When interlaced, a field does not contain adjacent scan lines and there is more than one field per frame.

Frame — One complete scanned image. The Robot 36-second color mode has 240 lines per frame

Frame Sequential — A method of color SSTV transmission that sent complete, sequential frames of red, then green and blue. Now obsolete.

Front porch — The blank part of a scan line just before the horizontal sync.

Interlace — Scan line ordering other than the usual sequential top to bottom. AVT "QRM" mode is the only SSTV mode that uses interlacing.

Line Sequential — A method of color SSTV transmission that sends red, green and blue information for each sequential scan line. This approach allows full-color images to be viewed during reception.

Luminance — The brightness component of a video signal. Usually computed as Y (the luminance signal) = 0.59 G (green) + 0.30 R (red) + 0.11 B (blue).

Martin — A family of amateur SSTV

transmission modes developed by Martin Emmerson, G3OQD, in England.

Pixel — Picture element. The dots that make up images on a computer's monitor.

P7 monitor — SSTV display using a CRT having a very-long-persistence phosphor.

RGB — Red, Green, Blue. One of the models used to represent colors. Due to the characteristics of the human eye, most colors can be simulated by various blends of red, green, and blue light.

Robot — (1) Abbreviation for Robot 1200C scan converter; (2) a family of SSTV transmission modes introduced with the 1200C.

Scan converter — A device that converts one TV standard to another. For example, the Robot 1200C converts SSTV to and from FSTV.

Scottie — A family of amateur SSTV transmission modes developed by Eddie Murphy, GM3SBC, in Scotland.

SSTV — Slow Scan Television. Sending still images by means of audio tones on the MF/HF bands using transmission times of a few seconds to a few minutes.

Sync — That part of a TV signal that indicates the beginning of a frame (vertical sync) or the beginning of a scan line (horizontal sync).

VIS — Vertical Interval Signaling. Digital encoding of the transmission mode in the vertical sync portion of an SSTV image. This allows the receiver of a picture to automatically select the proper mode. This was introduced as part of the Robot modes and is now used by all SSTV software designers.

Wraase — A family of amateur SSTV transmission modes first introduced with the Wraase SC-1 scan converter developed by Volker Wraase, DL2RZ, of Wraase Electronik, Germany.

DIGITAL SSTV TERMS

Bad segment report (BSR) — A DRM transmission that lists all the missing segments for a file that has only been partly received.

COFDM — Coded Orthogonal Frequency Division Multiplex, a method of using spaced subcarriers that are phased in such a way as to reduce the interference between them, plus coding to provide error correction and noise immunity.

Constellation — A set of points in the complex plane that represent the various combinations of phase and amplitude in a QAM or other complex modulation scheme.

Cyclic redundancy check (CRC) — A mathematical operation. The result of the CRC is sent with a transmission block. The receiving station uses the received CRC to check transmitted data integrity to determine if the data received is good or bad.

Digital Radio Mondiale (DRM) — A consortium of broadcasters, manufacturers, research and governmental organizations which developed a system for digital sound broadcasting in bands between 100 kHz and 30 MHz. Amateurs use a modified version for sending digital voice and images.

Error Protection — DRM submode selection. The HI level provides a greater amount of **FEC** used within the segment.

Fast access channel (FAC) — Auxiliary channel always modulated in 4QAM. Contains the submode and station information.

FIX — A DRM transmission that sends the data for all the segments for a received BSR.

FEC — Forward error correction, an error-control technique in which the transmitted data is sufficiently redundant to permit the receiving station to correct some errors.

LeadIn — The number of redundant segments sent at the beginning of the DRM file transmission to allow the receiving station to become synchronized.

Main service channel (MSC) — Contains the data. Can be modulated in 4QAM, 16QAM or 64QAM.

Mode — In digital SSTV, a particular submode of a DRM transmission. The amount of data in each segment is determined by the submode selected. Robustness varies for each submode.

QAM — Quadrature Amplitude Modulation. A method of simultaneous phase and amplitude modulation. The number that precedes it, for example 64QAM, indicates the number of discrete stages in each pulse.

Reed-Solomon error correction — A data encoding process that inserts redundant data so that errors in reading the data may be detected and corrected. *EasyPal* provides four levels ranging from Very Light Encode (RS1) to Heavy Encode (RS4).

Segment — One MSC frame of a DRM file transmission. Contains file name or transport ID and data.

TUNE — In DRM, a three-tone transmission used to set levels, check for IMD and adjust frequency.

12 SSTV Bibliography and References

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For links to more information on SSTV, visit the "CQ SSTV" website: **www.qsl.net/kb4yz.**